Chapter 6
Academic Research and Development: Financial and Personnel Resources, Support for Graduate Education, and Outputs

Contents

Highlights

Financial Resources for Academic R&D

- ♦ **In 1998, an estimated $26.3 billion (in current dollars) was spent for research and development (R&D) at U.S. academic institutions (equivalent to $23.4 billion in constant 1992 dollars).** The Federal Government provided $15.6 billion, the academic institutions $5.0 billion, state and local governments $2.1 billion, industry $1.9 billion, and other sources $1.8 billion.

- ♦ **Over the past 45 years (between 1953 and 1998), average annual R&D growth has been stronger for the academic sector than for any other R&D-performing sector.** During this period, academic R&D rose from 0.07 to 0.31 percent of gross domestic product (GDP), a more than fourfold increase.

- ♦ **The academic sector performs just under 50 percent of basic research, continuing to be the largest performer of basic research in the United States.** Academic R&D activities have been highly concentrated at the basic research end of the R&D spectrum since the late 1950s. Of estimated 1998 academic R&D expenditures, an estimated 69 percent went for basic research, 24 percent for applied research, and 7 percent for development.

- ♦ **The Federal Government continues to provide the majority of funds for academic R&D.** It provided an estimated 59 percent of the funding for R&D performed in academic institutions in 1998, down from its peak of 73 percent in the mid-1960s. Since 1994, non-Federal support has increased more rapidly than Federal support.

- ♦ **Three agencies are responsible for over four-fifths of Federal obligations for academic R&D: the National Institutes of Health (NIH—58 percent), the National Science Foundation (NSF—15 percent), and the Department of Defense (DOD—10 percent).** The National Aeronautics and Space Administration (5 percent), the Department of Energy (4 percent), and the Department of Agriculture (3 percent) provide an additional 12 percent of obligations for academic R&D. Federal agencies emphasize different science and engineering (S&E) fields in their funding of academic research, with some, such as NIH, concentrating their funding in one field and others, such as NSF, having more diversified funding patterns.

- ♦ **There has been a sizable increase in the number and types of universities and colleges receiving Federal R&D support during the past three decades.** Almost the entire increase occurred among other than research and doctorate-granting institutions, with 604 of these institutions receiving Federal R&D support in 1997, compared to 520 in 1990, 461 in 1980, and 341 in 1971. Although the share of Federal R&D support received by these institutions has increased over this period from 8 to 13 percent (rising from $0.4 billion to $1.5 billion in real terms), the research and doctorate-granting institutions continue to receive close to 90 percent of these funds.

- ♦ **After the Federal Government, academic institutions performing R&D provided the second largest share of academic R&D support.** After declining slightly in the early 1990s, the institutional share has been increasing since 1994, reaching an estimated 19 percent in 1998. Some of these funds directed by the institutions to research activities derive originally from Federal and state and local government sources, but—since the funds are not restricted to research, and the universities decide how to use them—they are classified as institutional funds.

- ♦ **Industrial R&D support to academic institutions has grown more rapidly** (albeit from a small base) **than support from all other sources during the past three decades.** Industry's share was an estimated 7 percent in 1998, its highest level since 1958. However, industrial support still accounts for one of the smallest shares of academic R&D funding.

- ♦ **Over half of academic R&D expenditures have gone to the life sciences during the past three decades.** In 1997, the life sciences accounted for 56 percent of total academic R&D expenditures, 54 percent of Federal academic R&D expenditures, and 58 percent of non-Federal academic R&D expenditures.

- ♦ **The distribution of Federal and non-Federal funding of academic R&D varies by field.** In 1997, the Federal Government supported close to 80 percent of academic R&D expenditures in both physics and atmospheric sciences, but only about 30 percent in political science and the agricultural sciences.

- ♦ **Total academic science and engineering research space increased by almost 28 percent between 1988 and 1998, up from about 112 million to 143 million net assignable square feet.** When completed, construction projects initiated between 1986 and 1997 are expected to produce over 63 million square feet of new research space, equivalent to about 45 percent of 1998 research space.

- ♦ **R&D equipment intensity—the percentage of total annual R&D expenditures from current funds devoted to research equipment—has declined dramatically during the past decade.** After reaching a high of 7 percent in 1986, it declined to 5 percent in 1997.

The Academic Doctoral Science and Engineering Workforce

- **Employment of doctoral scientists and engineers in academia reached a record 232,500 in 1997. Those with full-time faculty appointments were also at an all-time high of 178,400.** But faster growth outside the faculty ranks pushed the full-time faculty share of academic S&E employment to a low of 77 percent.

- **Doctoral employment at major research universities was stable over the decade; robust growth at other universities and colleges accelerated after 1995.**

- **Women accounted for the bulk of net growth in doctoral academic employment.** In 1997, 59,200 women represented one-quarter of employment and 22 percent of those in full-time faculty positions.

- **Doctoral academic minority employment reached 39,100 in 1997, with long-term increases generally in line with rising numbers of Ph.D. degrees earned.** American Indian, Alaskan Native, black, and Hispanic S&E doctorates comprised 6 percent of total employment and of faculty; Asians and Pacific Islanders were 11 percent of total employment.

- **The average age of the doctoral academic science and engineering faculty continues to rise.** Those 55 years or older constituted 13 percent of the total in 1973, 26 percent in 1997.

- **About 29,000 doctorates in the 1994–96 Ph.D. cohorts held academic positions in 1997. Forty-one percent each were in full-time faculty and postdoctoral positions.** In the early 1970s, 76 percent held faculty appointments, while 13 percent held postdoctorates.

- **Fewer than one-third of new science and engineering Ph.D.s hired by the research universities obtained full-time faculty appointments—less than half the percentage of the early 1970s.** In the other institutions, about 60 percent were hired into faculty positions.

- **The tenure-track fraction among young Ph.D.s with faculty appointments—about 75 percent—has remained roughly stable since the early 1970s.**

- **The physical sciences' shares of doctoral academic employment and full-time faculty have declined; the life sciences' shares have increased.** The bulk of the life sciences' growth took place in the nonfaculty segment, especially among postdoctorates.

- **The academic doctoral S&E research workforce—defined as those with research or development as their primary or secondary work responsibility—numbered an estimated 164,700 in 1997.** This represented a very robust 7 percent growth over 1995.

- **In 1997, 39 percent of the doctoral scientists and engineers in academia reported receiving support from the Federal Government.** This percentage has been stable in the 1990s.

- **The balance among S&E Ph.D.s reporting teaching or research as their *primary* activity has shifted toward research, for faculty and nonfaculty alike. But among *recent* Ph.D.s in faculty positions, trends in *primary* activity have reversed direction since the late 1980s:** Teaching rose from 56 percent to 68 percent; research declined from 38 percent to 23 percent.

Financial Support for S&E Graduate Education

- **In 1997, enrollment of full-time S&E graduate students registered a decline for the third consecutive year.** This period of decline followed steady increases in the enrollment of full-time S&E graduate students in every year since 1978.

- **The proportion of full-time graduate students in science and engineering with a research assistantship as their primary mechanism of support increased between 1980 and 1997.** Research assistantships were the primary support mechanism for 67 percent of the students whose primary source of support was from the Federal Government in 1997, compared to 55 percent in 1980. For students whose primary source was non-Federal, research assistantships rose from 20 percent to 29 percent of the total during this period. These shifts occurred primarily in the 1980s, and the relative usage of different types of primary support mechanisms has been fairly stable during the 1990s.

- **The Federal Government plays a larger role as the primary source of support for some support mechanisms than for others.** A majority of traineeships in both private and public institutions (54 percent and 73 percent, respectively) are financed primarily by the Federal Government, as are 60 percent of the research assistantships in private and 46 percent in public institutions.

- **The National Institutes of Health and National Science Foundation are the two Federal agencies that have been the primary source of support for full-time S&E graduate students relying on research assistantships as their primary support mechanism.** Each of these agencies supports about one-quarter of Federal graduate research assistantships. The Department of Defense supports about 15 percent.

- **Research assistantships are more frequently identified as a primary mechanism of support in the physical sciences, the environmental sciences, and engineering than in other disciplines.** Research assistantships comprise more than 50 percent of the primary support mechanisms for graduate students in atmospheric sciences, oceanography, agricultural sciences, chemical engineering, and materials engineering. They account for less than 20 percent in the social sciences, mathematics, and psychology.

Outputs of Scientific and Engineering Research

- **In the mid-1990s, approximately 173,200 scientific and technical articles per year were published by U.S. authors in a set of refereed U.S. journals included in the Science Citation Index (SCI) since 1985.** Seventy-three percent had academic authors; industrial, government, and nonprofit sector authors each contributed 7–8 percent.
- **The number of industrial articles declined by 12 percent, from an annual average of 15,050 in 1988–91 to 13,220 in 1995–97. Industrial article volume in physics fell by 40 percent over the period, but output rose strongly in clinical medicine (19 percent) and biomedical research (12 percent).** This trend signals a shift in publishing activity toward pharmaceutical and other life-sciences-oriented industry segments.
- **Increasingly, scientific collaboration within the United States involves scientists and engineers from different employment sectors. In 1997, 30 percent of all academic papers involved such cross-sectoral collaboration.** Other sectors' collaboration rates were higher: 65 percent for industrial papers and 68 percent for those from the government and nonprofit sectors.
- **Much of the growth in U.S. coauthorship reflects increases in international collaboration.** By the mid-1990s, nearly one of every five U.S. articles had one or more international coauthors, up from 12 percent earlier in the decade.
- **Globally, five nations produced more than 60 percent of the articles in the SCI set of journals:** the United States (34 percent), Japan (9 percent), the United Kingdom (8 percent), Germany (7 percent), and France (5 percent). No other country's output reached 5 percent of the total.
- **The development or strengthening of national scientific capabilities in several world regions resulted in a continuation of a long-term decline in the U.S. share of total article output.** Shares of Western European countries as a group and Asia increased. The number of U.S. articles declined by 4 percent from its high earlier in the decade, while those of Western Europe and Asia rose by 18 and 31 percent, respectively.
- **Countries' science portfolios, as reflected in their published output, show some striking differences.** In some, like the United States, United Kingdom, and many smaller European states, the bulk of the articles falls in the life sciences. In others, notably many Central and Eastern European and Asian countries, the share of articles in the physical sciences and engineering is higher.
- **The increasingly global nature of science is reflected in growing scientific collaboration. In 1997, half of the articles in a set of key world journals covered by the SCI had multiple authors; 30 percent of these coauthored articles involved international collaboration, compared to 23 percent a decade earlier.** This trend affected most nations and fields.
- **The international nature of science is further underscored by patterns of citation. Averaged across all nations, about 59 percent of all citations were to nondomestic articles, up from 53 percent early in the decade.** Citations to U.S. articles nearly always exceeded the volume of citations to the domestic literature.
- **Two trends characterize the position of the United States in international collaboration. For most nations with strong international coauthorships, the number of articles with U.S. coauthors rose.** But many nations broadened the reach of their international collaborations, causing a diminution of the U.S. share of the world's internationally coauthored articles.
- **The linkage between research and perceived economic utility is getting tighter. The percentage of U.S. patents citing scientific and technical articles as "prior art" increased strongly, from 11 percent of all patents in 1985 to 23 percent in 1995. The number of articles cited on these patents grew explosively from 8,600 in 1987 to 108,300 in 1998.** This trend was rooted in the extremely rapid rise of citations to biomedical research and clinical medicine, reflecting perceptions of the life sciences' economic potential and related patenting trends. However, it was not limited to these fields.
- **Academic institutions are seeking to realize financial benefits from their research results. The number of academic patents has risen thirteenfold since the early 1970s.** The 3,151 patents awarded in 1998 represented about 5 percent of U.S.-owned patents, up from 0.5 percent in the earlier period.
- **University patents in the three largest academic technology classes—all with presumed biomedical applicability—constituted 41 percent of all academic patents in 1998.** Overall, academic patents are concentrated in far fewer technology areas than are industrial patents, and are growing more so.
- **University gross income from patenting and licenses reached $483 million in 1997.** Half or more of total royalties were directly related to the life sciences.
- **The number of startups and of licenses and options granted increased strongly.** Forty-one percent of new licenses and options went to large firms, 48 percent to small existing companies, and 11 percent to startups.

Introduction

Chapter Background

This chapter addresses key aspects of the academic research and development (R&D) enterprise: financial resources, physical infrastructure, science and engineering (S&E) doctoral employment, financial support for S&E graduate education, and research outputs. Half a century ago, these same aspects were of sufficient concern to merit discussion in the two seminal reports focusing on the U.S. R&D system, *Science—The Endless Frontier* (Bush 1945) and *Science and Public Policy* (Steelman 1947).

Both the Bush and the Steelman reports stressed the critical importance of a Federal role in supporting academic research, recommending a major expansion of that role. Today, that vision has materialized. A strong national consensus supports the public funding of academic research, and the Federal Government provides roughly 60 percent of the financial resources for academic R&D. A number of contemporary issues have arisen relating to this support; the appropriate balance of funding across S&E disciplines and accountability requirements—including measuring outputs and larger social outcomes—are examples.

The Steelman report focused on an aspect of the academic R&D enterprise that has become an enduring concern: broadening and strengthening the academic base of the Nation's science and engineering and R&D enterprise. Talent was sure to be found everywhere, and the Steelman report recommended using a portion of National Science Foundation (NSF) funds to strengthen weaker but promising colleges and universities in order to increase U.S. scientific potential. In point of fact, the number of academic institutions receiving Federal support for R&D activities has increased dramatically since the issuance of the report.

The Steelman report also noted that research facilities were less adequate at universities and colleges than elsewhere and called for additional libraries, laboratory space, and equipment and for Federal aid to academic institutions for the construction of facilities and purchase of equipment. Except for a decade during the 1960s and early 1970s, when a number of agencies conducted broad institutional support programs, the Federal Government has not taken a major role in providing direct support to universities and colleges for the construction of their research facilities. In recent years, it has accounted for about 8 to 9 percent of the funds for laboratory construction and renovation, with the institutions providing over 60 percent. In contrast, the Federal Government has accounted for almost 60 percent of direct current funds expenditures for academic research equipment during the past two decades. The Federal Government also indirectly supports both facilities and equipment through reimbursement on Federal grants and contracts.

The Steelman report placed strong emphasis on human resources development. An early chapter bears the title "Manpower: The Limiting Resource" and noted a broad disparity in the growth paths of the Nation's R&D budget and highly trained personnel. While recommending strong increases in R&D funding, the report recognized the need to alleviate inadequate personnel resources. It pointed to the critical role of doctoral science and engineering faculty in the universities and colleges, noting both their teaching and their research responsibilities. The report estimated that it would take an additional 15,000 such faculty to restore the prewar student-teacher ratio, while also expanding the sector's capacity for research. The discussion of these issues in recent years has been quite different, focusing on a burgeoning supply of new science and engineering Ph.D.s and a sometimes-variable labor market for other degree-holders, punctuated by debates about shortages and oversupply.

Both the Bush and the Steelman reports focused on an issue that has drawn increasing attention over the past decade—the importance of integrating education and research in higher education. They stressed that research is required for the teaching of science, and that fully trained scientists can only be produced through involvement in research. The Steelman report noted that the recommended expansion of academic research grants would result in the employment of graduate students as research assistants, which in turn would result in better scientific training. Research assistantships now comprise the largest primary graduate student support mechanism; two-thirds of federally supported students receive their support in the form of a research assistantship. A number of Federal graduate traineeship programs, and even more recently some Federal graduate fellowship programs, have emphasized the integration of education and research.

Half a century ago, the Steelman and Bush reports largely took for granted the positive outcomes and impacts of research and development. Today's mature and established publicly funded R&D system faces new demands, not envisioned then, of devising means and measures to account for the proximate outputs of specific Federal R&D investments, including those for academic R&D, and their longer-term consequences for valued social ends.

Even though the academic R&D enterprise has enjoyed strong growth for the past several decades, the Nation's universities and colleges face challenges in their finances, enrollment, faculty, and competitive environment. Many of these factors will have some form of impact on the academic R&D enterprise. This chapter seeks to provide data on some pertinent trends and analysis bearing on these issues.

Chapter Organization

The chapter opens with a discussion of trends in the financial resources provided for academic R&D, including allocations across both academic institutions and S&E fields. Because the Federal Government has been the primary source of support for academic R&D for over half a century, the importance of selected agencies in supporting individual fields is explored in some detail. Data are also presented on changes in the number of academic institutions receiving Federal R&D support. The section then examines the status of two key elements of university research activities—facilities and instrumentation.

Basic Research

Science and Public Policy (Steelman report)
Part One—Science for the Nation, IV. A National Science Program

Basic research traditionally has been conducted in the colleges and universities. While industry engages in some basic research and the Government laboratories conduct a somewhat greater amount, the proportions in both instances are small. The principal function of the colleges and universities is to promote the progress of learning and they must be the primary means through which any expanded program of basic research is carried out. There are several reasons for this.

First, the scientific method, being based upon experiment, requires research for the teaching of science. Fully trained scientists can be produced only through practicing research.

Second, basic research is so broad in its application and so indirectly related to any industrial process, or in fact to any particular industry, that it is not profitable for private enterprise to engage in extensive basic research. Industries do sometimes support it through fellowships and other grants to universities, but the sums involved are not large.

Third, research, while carried out by individuals, has always been a cooperative venture. Scientists have exchanged information and collaborated with each other in the performance of research; and science progresses characteristically through a combination of knowledge from many different sources. Research thrives in situations where scientists with many diverse interests and fields of knowledge can be brought together in an exchange of both knowledge and ideas. Thus the universities, which foster all branches of knowledge, are ideal breeding grounds for basic research. (Steelman 1947, 29.)

The next section discusses trends in the employment, demographic characteristics, and activities of academic doctoral scientists and engineers. The discussion of employment trends focuses on full-time faculty, postdoctorates, and other positions. Differences are examined between the Nation's largest research universities and other academic institutions, as are shifts in the faculty age structure. The involvement of women, underrepresented minorities, and Asians and Pacific Islanders is also examined. Attention is given to participation in research by academic doctoral scientists and engineers, the relative balance between teaching and research, and the Federal support they report for their research. Selected demographic characteristics of recent doctorate-holders entering academic employment are examined.

The third section looks at the relationships between research and graduate education. It covers overall trends in graduate support and patterns of support in different types of institutions, and compares support patterns for those who complete an S&E doctorate with the full population of graduate students. The role of graduate research assistantships is examined in some detail, including the sources of support for research assistants and the spreading incidence of research assistantship (RA) support to a growing number of academic institutions.

The chapter's final section deals with two research outputs: scientific and technical articles in a set of journals covered by the Science Citation Index (SCI), and patents issued to U.S. universities. (A third major output of academic R&D, educated and trained personnel, is discussed in the preceding section of this chapter and in chapter 4.) The section specifically looks at the output volume of research (article counts), collaboration in the conduct of research (joint authorship), use in subsequent scientific activity (citation patterns), and use beyond science (citations to the literature on patent applications). It concludes with a discussion of academic patenting and some returns to academic institutions from their patents and licenses.

Financial Resources for Academic R&D[1]

Academic R&D is a significant part of the national R&D enterprise. Enabling U.S. academic researchers to carry out world-class research requires adequate financial support as well as excellent research facilities and high-quality research equipment. Consequently, assessing how well the academic R&D sector is doing, the challenges it faces, and how it is responding to those challenges requires data and information relating to a number of important issues that relate to the financing of academic R&D. Among these issues are the level and stability of overall funding; the sources of funding and changes in their relative importance; the distribution of funding among the different R&D activities (basic research, applied research, and development); the balance of funding among science and engineering fields and subfields or fine fields; the distribution of funding among and the extent of participation of various types of academic R&D performers; the changing role of the Federal Government as a supporter of academic R&D and the particular roles of the major Federal agencies funding this sector; and the state of the physical infrastructure—research facilities and equipment—that is a necessary input to the sector's success. This section focuses on providing data on these aspects of the academic R&D enterprise which individually and in combination influence its evolution.

[1]Data in this section come from several different National Science Foundation (NSF) surveys that do not always use comparable definitions or methodologies. NSF's three main surveys involving academic R&D are the (1) Survey of Federal Funds for Research and Development; (2) Survey of Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions; and (3) Survey of Research and Development Expenditures at Universities and Colleges. The results from this last survey are based on data obtained directly from universities and colleges; the former two surveys collect data from Federal agencies. For descriptions of the methodologies of these and other NSF surveys, see NSF (1995b and 1995c).Federally Funded Research and Development Centers associated with universities are tallied separately and are examined in greater detail in chapter 2.

Academic R&D in the National R&D Enterprise[2]

The continuing importance of academe to the Nation's overall R&D effort is still recognized today, especially its contribution to the generation of new knowledge through basic research.

In 1998, an estimated $26.3 billion, or $23.4 billion in constant 1992 dollars, was spent on R&D at U.S. academic institutions.[3] This was the 24th consecutive year in which constant dollar spending increased from the previous year. Academia's role as an R&D performer has increased fairly steadily during the past half-century, rising from about 5 percent of all R&D performed in the country in 1953 to almost 12 percent in 1998. (See figure 6-1.) However, since 1994, the sector's performance share has dipped slightly from its high of almost 13 percent (see "Growth" section below). For a description of the role of universities in national R&D expenditures in the first part of the 20th century, see chapter 1, "Science and Technology in Times of Transition: the 1940s and 1990s."

Character of Work

Academic R&D activities are concentrated at the research (basic and applied) end of the R&D spectrum and do not include much development activity.[4] Of 1998 academic R&D expenditures, an estimated 93 percent went for research (69 percent for basic and 24 percent for applied) and 7 percent for development. (See figure 6-2.) From a national research—as opposed to national R&D—perspective, academic institutions accounted for an estimated 27 percent of the U.S. total in 1998. The academic share of research almost doubled, from about 14 percent of the U.S. total in the 1950s to around 26 percent in the first half of the 1970s. It has since fluctuated between 23 and 30 percent. And, in terms of basic research alone, the academic sector is the country's largest performer, currently accounting for an estimated 48 percent of the national total. Between 1953 and 1972, the academic sector's basic research performance grew steadily, increasing from about one-quarter to just over one-half of the national total. It has since fluctuated between 45 and 51 percent of the national total. (See figure 6-1.)

Growth

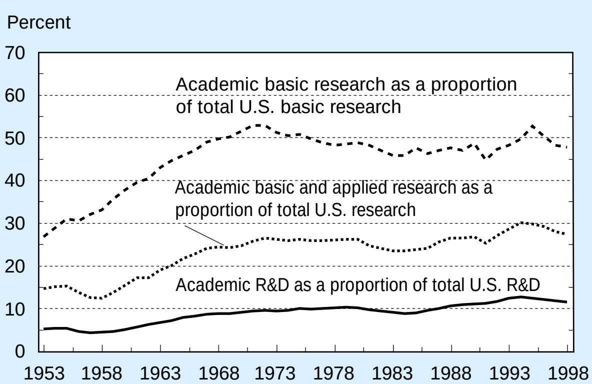
Over the long term (between 1953 and 1998), average annual R&D growth (in constant 1992 dollars) has been stronger for the academic sector than for any other R&D-performing sector—6.5 percent, compared to about 5.7 per-

[2]For more information on national R&D expenditures, see "Economic Measures of R&D" in chapter 2.

[3]For the purposes of this discussion, academic institutions generally comprise institutions of higher education that grant doctorates in science or engineering and/or spend at least $50,000 for separately budgeted R&D. In addition, all Historically Black Colleges and Universities (HBCUs) with R&D programs are included, regardless of the level of R&D.

[4]Notwithstanding this delineation, the term "R&D"—rather than just "research"—is used throughout this discussion unless otherwise indicated, since much of the data collected on academic R&D does not differentiate between "R" and "D." Moreover, it is often difficult to make clear distinctions among basic research, applied research, and development. For the definitions used in NSF resource surveys, see chapter 2.

Figure 6-1.
Academic R&D, research, and basic research as a proportion of U.S. totals: 1953–98

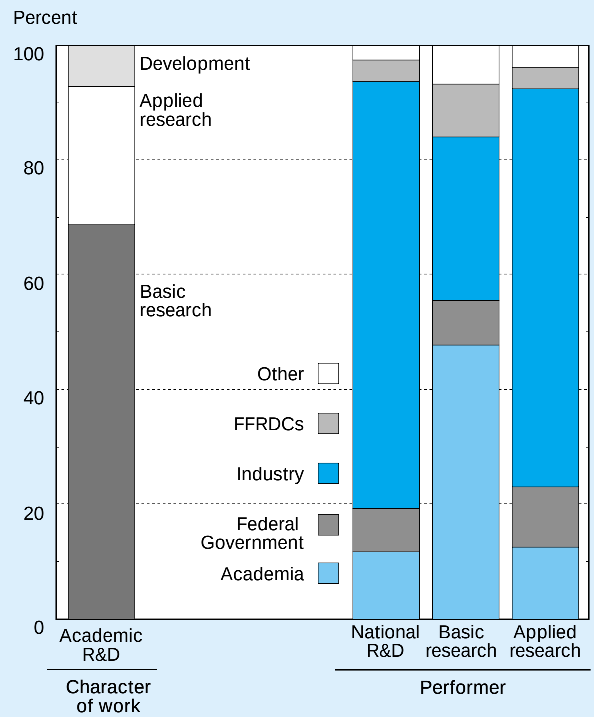


NOTE: Data for 1998 are preliminary.

See appendix tables 2-3, 2-7, and 2-11.

Science & Engineering Indicators – 2000

Figure 6-2.
Academic R&D expenditures by character of work and national R&D expenditures by performer and character of work: 1998



FFRDC = Federally Funded Research and Development Center

NOTE: Data are preliminary.

See appendix tables 2-3, 2-7, 2-11, and 6-1.

Science & Engineering Indicators – 2000

cent for federally funded research and development centers (FFRDCs), 5.2 percent for other nonprofit laboratories, 4.8 percent for industrial laboratories, and 2.5 percent growth for Federal laboratories. (See appendix table 2-4 for time series data by R&D-performing sector.) This long-term trend has held for more recent times as well—through the 1980s and the early part of the 1990s—although average annual growth was higher for all R&D-performing sectors between 1953 and 1980 than it has been since 1980. However, beginning in 1994 growth of R&D performed in industry (an estimated 7.6 percent annually) started to outpace growth of academically performed R&D (an estimated 3.2 percent annually). As a proportion of gross domestic product (GDP), academic R&D rose from 0.07 to 0.31 percent between 1953 and 1998, a more than fourfold increase. (See appendix table 2-1 for GDP time series.)

University R&D Expenditures

Science and Public Policy (Steelman report)
Part One—Science for the Nation, IV.
A National Science Program

There is every reason to anticipate a doubling of research and development expenditures by industry in the next decade, in view of the long term trends and the increasing dependence of industry upon research and development. But there is little likelihood of any considerable expansion of university expenditures out of their present income sources. Endowment income has sharply declined over the last 15 years and there is little likelihood of any considerable rise in interest rates in the future. Moreover, the large fortunes which were the source of new endowment funds are now considerably limited by taxation. So far as State-supported institutions are concerned, the long-run financial position of many states makes large increases in university support unlikely. A similar situation confronts the private foundations, which are not, in any event, of great significance in the over-all financial picture. The foundations have contributed enormously to the extension of knowledge and to the support of basic research, but their expenditures have been small in terms of the total budget. It is not likely that their share will expand in the future. (Steelman 1947, 26-7.)

Major Funding Sources

The continued reliance of the academic sector on a variety of funding sources for support of its R&D activities requires continuous monitoring of the contributions of those sources.

The Federal Government continues to provide the majority of funds for academic R&D. In 1998, it accounted for an estimated 59 percent of the funding for R&D performed in academic institutions. After increasing from 55 percent in 1953 to its peak of just over 73 percent in 1966, the Federal support share declined fairly steadily until the early 1990s. (See figure 6-3.) Since 1992, it has fluctuated between 59 and 60 percent. The Federal sector primarily supports basic research—72 percent of its 1998 funding went to basic research versus 20 percent to applied. Non-Federal sources also concentrate on basic research, but provide a larger share of their support than the Federal sector for applied research (64 percent for basic and 30 percent for applied research). (See appendix table 6-1.) As a consequence of this differential emphasis, 62 percent of the basic research performed at universities and colleges is supported by the Federal Government, while only 49 percent of the applied research is so supported.

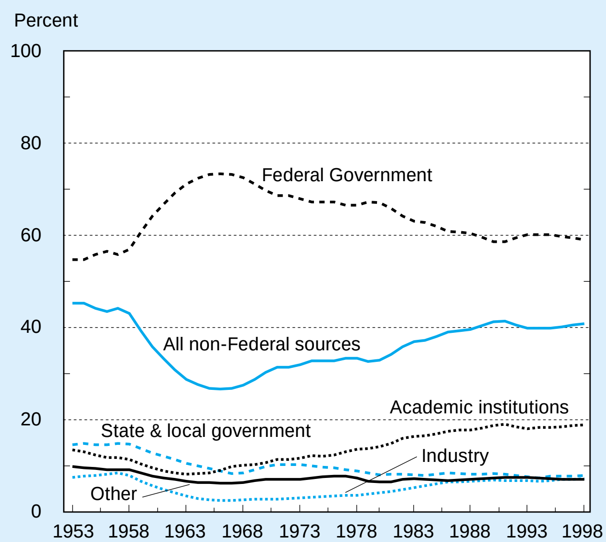
Federal support of academic R&D is discussed in detail later in this section; the following summarizes the contributions of other sectors to academic R&D.[5]

- ♦ **Institutional funds.**[6] In 1998, institutional funds from universities and colleges constituted the second largest source of academic R&D funding, accounting for an estimated 19 percent. The share of support represented by this source has been increasing fairly steadily since the early 1960s, save for a brief downturn in the early 1990s. Institutional

[5]The academic R&D funding reported here includes only separately budgeted R&D and institutions' estimates of unreimbursed indirect costs associated with externally funded R&D projects, including mandatory and voluntary cost sharing. It does not include departmental research, and thus will exclude funds—notably for faculty salaries—in cases where research activities are not separately budgeted.

[6]Institutional funds are separately budgeted funds that an academic institution spends on R&D from unrestricted sources, unreimbursed indirect costs associated with externally funded R&D projects, and mandatory and voluntary cost sharing on Federal and other grants. As indicated above, departmental research that is not separately budgeted is not included.

Figure 6-3.
Sources of academic R&D funding: 1953–98



NOTE: Data for 1998 are preliminary.

See appendix table 6-2. *Science & Engineering Indicators – 2000*

R&D funds may be derived from (1) general-purpose state or local government appropriations, particularly for public institutions; (2) general-purpose grants from industry, foundations, or other outside sources; (3) tuition and fees; (4) endowment income; and (5) gifts that are not restricted by the donor to conduct research. Other potential sources of institutional funds are income from patents or licenses and income from patient care revenues. (See "Academic Patenting: Patent Awards, Licenses, Startups, and Revenue" later in this chapter for a discussion of patent and licensing income.)

- **State and local government funds.** In 1998, the share of academic R&D funding provided by state and local governments was an estimated 8 percent. State and local governments played a larger role during the early 1950s, when they provided about 15 percent of the funding. Their relative role began to decline thereafter except for a brief upturn between 1968 and 1973. Their share of academic R&D funding has fluctuated between 7 and 8 percent since 1980. This share, however, reflects only funds directly targeted to academic R&D activities by the state and local governments and does not include general-purpose state or local government appropriations that academic institutions designate and use for separately budgeted research or to cover unreimbursed indirect costs.[7] Consequently, the actual contribution of state and local governments to academic R&D is understated, particularly for public institutions.

- **Industry funds.** In 1998, industry provided an estimated 7 percent of academic R&D funding. The funds provided for academic R&D by the industrial sector grew faster than funding from any other source during the past three decades, although industrial support still accounts for one of the smallest shares of funding. During the 1950s, industry's share was actually larger than it is currently, peaking at 8.4 percent in 1957. After reaching this peak, the industrial share steadily declined, reaching its low of 2.5 percent in 1966. Industry then began to increase its share from slightly below 3 percent in 1970, to about 4 percent in 1980 and about 7 percent in 1990, where it has since remained. Industry's contribution to academia represented an estimated 1.3 percent of all industry-funded R&D in 1998, compared to 0.9 percent in 1980, 0.6 percent in 1970, and 1.1 percent in 1958. (See appendix tables 2-4 and 2-5 for time series data on industry-funded R&D.) Thus, although increasing recently, industrial funding of academic R&D has never been a major component of industry-funded R&D.

- **Other sources of funds.** In 1998, other sources of support accounted for 7 percent of academic R&D funding. This share has stayed fairly constant at about this level during the past three decades after declining from its peak of 10 percent in 1953. These sources include grants for R&D from nonprofit organizations and voluntary health agencies and gifts from private individuals that are restricted by the donor to conduct research, as well as all other sources restricted to research purposes not included in the other categories.

[7]This follows international standards of reporting where funds are assigned to the entity determining how they are to be used rather than to the one necessarily providing the funds.

Funding by Institution Type

Although public and private universities rely on the same funding sources for their academic R&D, the relative importance of those sources differs substantially for these two types of institutions. (See appendix table 6-3.) For all *public* academic institutions combined, just over 10 percent of R&D funding in 1997—the most recent year for which data are available—came from state and local funds, about 23 percent from institutional funds, and about 53 percent from the Federal Government. *Private* academic institutions received a much smaller portion of their funds from state and local governments (about 2 percent) and from institutional sources (10 percent), and a much larger share from the Federal Government (72 percent). The large difference in the role of institutional funds between public and private institutions is most likely due to a substantial amount of general-purpose state and local government funds received by the former that these institutions decide to use for R&D (although data on such breakdowns are not collected). Both public and private institutions received approximately 7 percent of their respective R&D support from industry in 1997. Over the past two decades, the Federal share of support has declined, and the industry and institutional shares have increased, for both public and private institutions.

Distribution of R&D Funds Across Academic Institutions

The nature of the distribution of R&D funds across academic institutions has been and continues to be a matter of interest to those concerned with the academic R&D enterprise. Most academic R&D is now, and has been historically, concentrated in relatively few of the 3,600 higher education institutions in the United States.[8] In fact, if all such institutions were ranked by their 1997 R&D expenditures, the top 200 institutions would account for about 95 percent of R&D expenditures. In 1997 (see appendix table 6-4[9]):

[8]The Carnegie Foundation for the Advancement of Teaching classified about 3,600 degree-granting institutions as higher education institutions in 1994. (See chapter 4 sidebar, "Carnegie Classification of Institutions," for a brief description of the Carnegie categories.) These higher education institutions include four-year colleges and universities, two-year community and junior colleges, and specialized schools such as medical and law schools. Not included in this classification scheme are more than 7,000 other postsecondary institutions (secretarial schools, auto repair schools, and so forth.).

[9]The Johns Hopkins University and the Applied Physics Laboratory (APL) at the Johns Hopkins University are reported separately in appendix table 6-4. Although not officially classified as an FFRDC, APL essentially functions as one. Separate reporting therefore provides a better measure of the distribution of academic R&D dollars and the ranking of individual institutions.

Other Assistance

Science and Public Policy (Steelman report)
Part One—Science for the Nation, IV.
A National Science Program

While the support of basic research through the National Science Foundation is of the utmost importance, it is only one of several elements in our total national science program. Moreover, it is only one element in our developing program of Federal support for higher education...Few persons would doubt today that we must soon develop a permanent, long-range program of Federal assistance to students and of Federal aid to education in general. Viewed in perspective, the support of basic research in the colleges and universities is part of such a program. It can achieve results only as the colleges and universities themselves are strong and only as means are found to permit able students to pursue their studies.

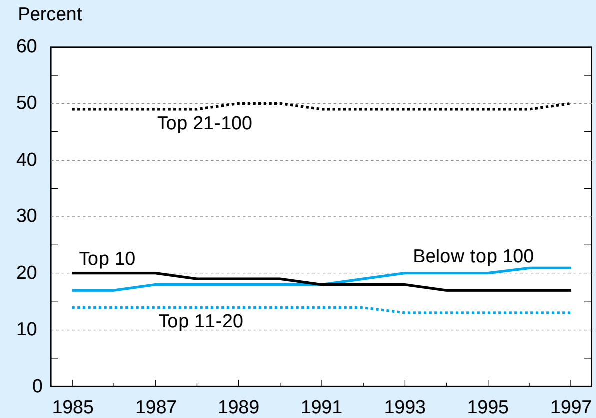
In such terms, it is clear that a portion of the funds expended by the National Science Foundation should be used to strengthen the weaker, but promising, colleges and universities, and thus to increase our total scientific potential. (Steelman 1947, 34.)

[For a discussion of a Federal program created to strengthen research and education in the sciences and engineering and to avoid undue concentration of such research and education, see sidebar, "EPSCoR—the Experimental Program to Stimulate Competitive Research."]

- the top 10 institutions spent 17 percent of total academic R&D funds ($4.1 billion),
- the top 20 institutions spent 30 percent ($7.3 billion),
- the top 50 spent 56 percent ($13.6 billion), and
- the top 100 spent 79 percent ($19.3 billion).

This historic concentration of academic R&D funds, however, has been diminishing somewhat over the past dozen years. (See figure 6-4.) In 1985, the top 10 institutions received about 20 percent and the top 11–20 institutions 14 percent of the funds, compared to 17 and 13 percent, respectively, in 1997. The composition of the universities in the top 20 has also fluctuated slightly over the period. There was almost no change in the share of the group of institutions ranked 21–100 during this period. The decline in the top 20 institutions' share was matched by the increase in the share of those institutions in the group below the top 100—this group's share increased from 17 to 21 percent of total academic R&D funds. This increased share of the Nation's total academic R&D expenditures by those institutions ranked below the top 100 signifies a broadening of the base. See "The Spreading Institutional Base of federally Funded Academic R&D" in

Figure 6-4.
Share of academic R&D of top R&D universities and colleges: 1985–97



See appendix table 6-4. *Science & Engineering Indicators – 2000*

the "Federal Support of Academic R&D" section below for a discussion of the increase in the number of academic institutions receiving Federal support for their R&D activities over the past three decades.

Expenditures by Field and Funding Source[10]

The distribution of academic R&D funds across S&E disciplines is often the unplanned result of numerous, sometimes unrelated, decisions and therefore needs to be monitored and documented to ensure that it remains appropriately balanced.

The overwhelming share of academic R&D expenditures in 1997 went to the life sciences, which accounted for 56 percent of total academic R&D expenditures, 54 percent of Federal academic R&D expenditures, and 58 percent of non-Federal academic R&D expenditures. Within the life sciences, medical sciences accounted for 28 percent of total academic R&D expenditures and biological sciences for 17 percent.[11] The next largest block of total academic R&D expenditures was for engineering—16 percent in 1997. (See appendix table 6-5.)

The distribution of Federal and non-Federal funding of academic R&D in 1997 varied by field. (See appendix table 6-5.) For example, the Federal Government supported close to 80 percent of academic R&D expenditures in both physics and atmospheric sciences, but only 30 percent of academic R&D in political science and 29 percent in the agricultural sciences.

[10]The data in this section are drawn from NSF's Survey of Research and Development Expenditures at Universities and Colleges. For various methodological reasons, parallel data by field from the NSF Survey of Federal Funds for Research and Development do not necessarily match these numbers.

[11]Medical sciences includes research in fields such as pharmacy, veterinary medicine, anesthesiology, and pediatrics. Biological sciences includes research in fields such as microbiology, genetics, biometrics, and ecology. These distinctions may be blurred at times, as the boundaries between fields are often not well defined.

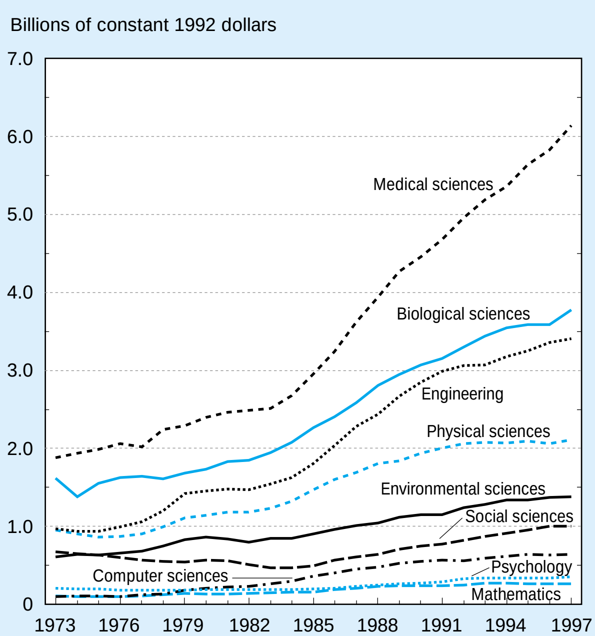
The declining Federal share in support of academic R&D is not limited to particular S&E disciplines. Rather, the federally financed fraction of support for each of the broad S&E fields was lower in 1997 than in 1973, except for the computer sciences (which was slightly higher). (See appendix table 6-6.) The most dramatic decline occurred in the social sciences—down from 57 percent in 1973 to 37 percent in 1997. The overall decline in Federal share also holds for all the reported fine S&E fields. However, most of the declines occurred in the 1980s, and most fields have not experienced declining Federal shares during the 1990s.

Although academic R&D expenditures in constant dollars for every field have increased between 1973 and 1997 (see figure 6-5 and appendix table 6-7), the R&D emphasis of the academic sector, as measured by its S&E field shares, has changed during this period.[12] (See figure 6-6.) Absolute shares of academic R&D have:

- ♦ increased for the life sciences, engineering, and computer sciences;
- ♦ remained roughly constant for mathematics; and
- ♦ declined for the social sciences, psychology, the environmental (earth, atmospheric, and oceanographic) sciences, and the physical sciences.

[12]For a more detailed discussion of these changes, see *How Has the Field Mix of Academic R&D Changed?* (NSF 1999g).

Figure 6-5.
Academic R&D expenditures, by field: 1973–97



NOTE: See appendix table 2-1 for GDP implicit price deflators used to convert current dollars to constant 1992 dollars.

See appendix table 6-7. *Science & Engineering Indicators – 2000*

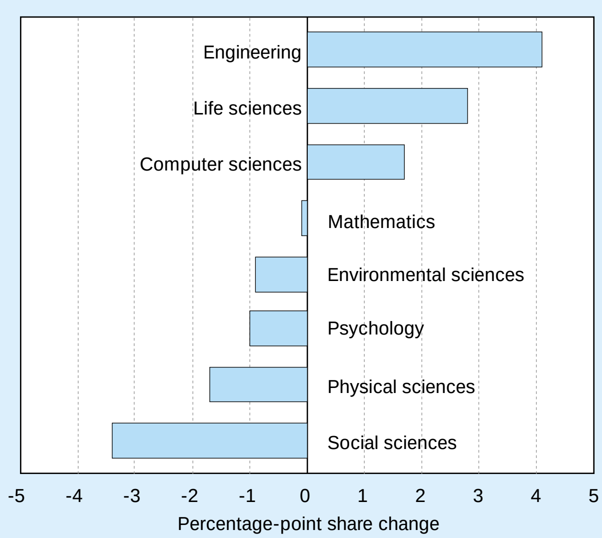
Although the proportion of the total academic R&D funds going to the life sciences' share increased by only 3 percentage points, rising from 53 to 56 percent of academic R&D between 1973 and 1997, the medical sciences' share increased by almost 6 percentage points—from 22 to 28 percent of academic R&D—during this period. The other two major components of the life sciences—agricultural sciences and biological sciences—both lost shares during the period. The engineering share increased by 4 percentage points over this period—from 12 to 16 percent of academic R&D; while the computer sciences' share increased from 1 to 3 percent of academic R&D.

The social sciences' proportion declined by more than 3 percentage points (from 8 to below 5 percent of academic R&D) between 1973 and 1997. Within the social sciences, the R&D shares for each of the three main fields—economics, political science, and sociology—declined over the period. Psychology's share declined by 1 percentage point (from 3 to 2 percent of academic R&D). The environmental sciences' share also declined by 1 percentage point (from 7 to 6 percent). Within the environmental sciences, the three major fields—atmospheric sciences, earth sciences, and oceanography—each experienced a decline in share. The physical sciences' share also declined during this period, from 11 to 10 percent. However, within the physical sciences, astronomy's share increased while the shares of both physics and chemistry declined.

Federal Support of Academic R&D

Although the Federal Government continues to provide the majority of the funding for academic R&D, its overall contribution is the combined result of decisions by a number of key

Figure 6-6.
Changes in the share of academic R&D in selected S&E fields: 1973–97



See appendix table 6-7. *Science & Engineering Indicators – 2000*

From Vannevar Bush in Science—The Endless Frontier:

One of our hopes is that after the war there will be full employment. To reach that goal the full creative and productive energies of the American people must be released. To create more jobs, we must make new and better and cheaper products. We want plenty of new, vigorous enterprises. But new products and processes are not born full-grown. They are founded on principles and new conceptions which in turn result from basic scientific research. Basic scientific research is scientific capital. Clearly, more and better scientific research is one essential to the achievement of our goal of full employment.

How do we increase this scientific capital? First, we must have plenty of men and women trained in science, for upon them depends both the creation of new knowledge and its application to practical purposes. Second, we must strengthen the centers of basic research which are principally the colleges, universities, and research institutes. These institutions provide the environment which is most conducive to the creation of new scientific knowledge and least under pressure for immediate, tangible results. With some notable exceptions, most research in industry and in Government involves application of existing scientific knowledge to practical problems. It is only the colleges, universities, and a few research institutes that devote most of their research efforts to expanding the frontiers of knowledge. (Bush 1945.)

funding agencies with differing missions.[13] Examining and documenting the funding patterns of these agencies are key to understanding both their roles and the overall government role.

Top Agency Supporters

Three agencies are responsible for most of the Federal obligations for academic R&D: the National Institutes of Health (NIH), the National Science Foundation (NSF), and the Department of Defense (DOD). (See appendix table 6-8.) Together, these agencies are estimated to have provided approximately 83 percent of total Federal financing of academic R&D in 1999, as follows:

- NIH—58 percent,
- NSF—15 percent, and
- DOD—10 percent.

An additional 12 percent of the 1999 obligations for academic R&D are estimated to be provided by the National Aeronautics and Space Administration (NASA, 5 percent); the Department of Energy (DOE, 4 percent); and the Department of Agriculture (USDA, 3 percent). Federal obligations for academic research are concentrated similarly to those for R&D. (See appendix table 6-9.) There are some differences, however, since agencies such as DOD place greater emphasis on development, while others such as NSF place greater emphasis on research.

During the 1990s, NIH's funding of academic R&D increased most rapidly, with an estimated average annual growth rate of 3.7 percent per year in constant 1992 dollars. NSF (3.2 percent) and NASA (2.4 percent) experienced the next highest rates of growth. Average annual rates of growth were negative for DOD, DOE, and USDA during this period. Between 1998 and 1999, total Federal obligations for academic R&D are estimated to increase by 5.4 percent in constant dollars. NSF (by 11 percent) and NIH (by 8 percent) are expected to have the largest increases in their academic R&D obligations in 1999.

Agency Support by Field

Federal agencies emphasize different S&E fields in their funding of academic research. Several agencies concentrate their funding in one field—the Department of Health and Human Services (HHS) and USDA focus on the life sciences, while DOE concentrates on the physical sciences. Other agencies—NSF, NASA, and DOD—have more diversified funding patterns. (See figure 6-7.) Even though an agency may place a large share of its funds in one field, it may not be a leading contributor to that field, particularly if it does not spend much on academic research. (See figure 6-8.) NSF is the lead funding agency in the physical sciences (34 percent of total funding), mathematics (66 percent), the environmental sciences (46 percent), and the social sciences (38 percent). DOD is the lead funding agency in the computer sciences (48 percent) and in engineering (39 percent). HHS is the lead funding agency in the life sciences (87 percent) and psychology (89 percent). Within fine S&E fields, other agencies take the leading role—DOE in physics (53 percent), USDA in agricultural sciences (99 percent), and NASA in astronomy (77 percent) and in both aeronautical (70 percent) and astronautical (65 percent) engineering. (See appendix table 6-11.)

The Spreading Institutional Base of Federally Funded Academic R&D

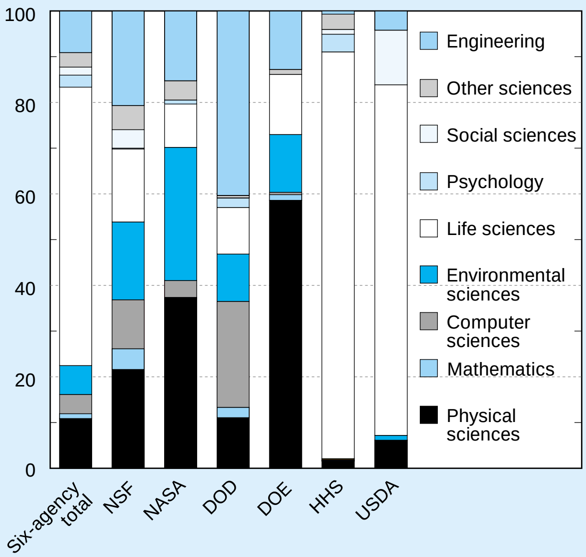
The number of academic institutions receiving Federal support for their R&D activities has increased over the past three decades.[14] Although that number has fluctuated during this time period,[15] there was an increase of almost 50 percent in the number of institutions receiving support in 1997, com-

[13]Some of the Federal R&D funds obligated to universities and colleges are the result of appropriations that Congress directs Federal agencies to award to projects that involve specific institutions. These funds are known as congressional earmarks. See Brainard and Cordes (1999) for a discussion of this subject.

[14]The data in this section are drawn from NSF's Survey of Federal Support to Universities, Colleges, and Nonprofit Institutions. The survey collects data on Federal R&D obligations to individual U.S. universities and colleges from the 15 Federal agencies that account for virtually all such obligations. For various methodological reasons, data reported in this survey do not necessarily match those reported in the Survey of Research and Development Expenditures at Universities and Colleges.

[15]The rather large decline in the number of institutions receiving Federal R&D support in the early 1980s was most likely due to the fall in Federal R&D funding for the social sciences during that period.

Figure 6-7.
Distribution of Federal agency academic research obligations, by field: FY 1997

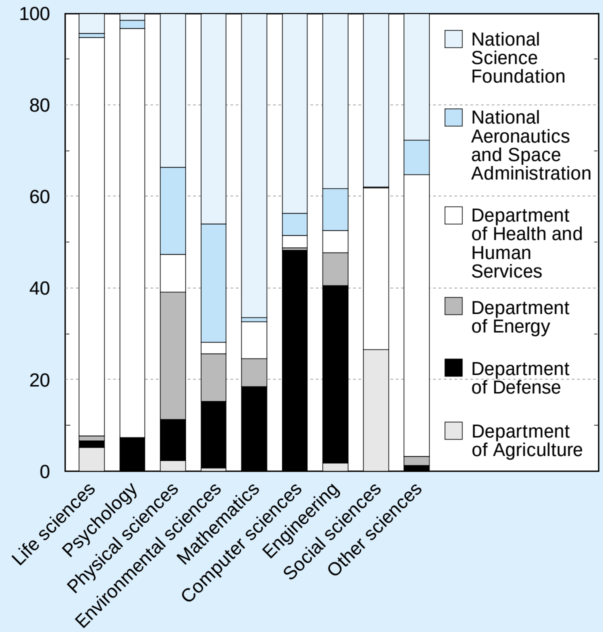


NSF = National Science Foundation; NASA = National Aeronautics and Space Administration; DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; USDA = Department of Agriculture

NOTE: The six agencies reported represent approximately 96 percent of Federal academic research obligations.

See appendix table 6-10. *Science & Engineering Indicators – 2000*

Figure 6-8.
Major agency field shares of Federal academic research obligations: FY 1997



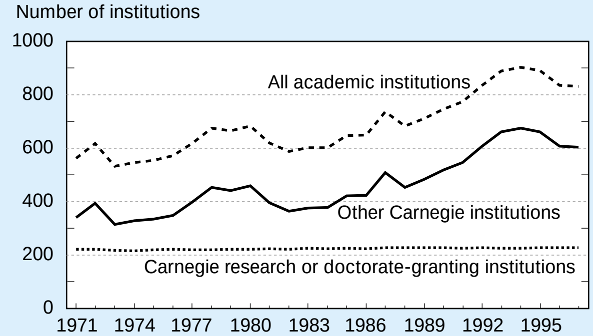
NOTE: The six agencies reported represent approximately 96 percent of Federal academic research obligations.

See appendix table 6-11. *Science & Engineering Indicators – 2000*

pared to 1971. (See figure 6-9.) Since most institutions currently designated as Carnegie research and doctorate-granting institutions were already receiving Federal support in 1971, most of the increase has occurred among the group containing comprehensive; liberal arts; two-year community, junior, and technical; and professional and other specialized schools.[16] The number of such institutions receiving Federal support just about doubled between 1971 and 1994, rising from 341 to 676. Since 1994, although the number of Carnegie research and doctorate-granting institutions receiving Federal R&D support has remained constant, there has been a rather substantial drop in the number of other institutions—from their peak of 676 to only 604 in 1997. However, most of the drop occurred in institutions receiving less than $100,000 in Federal R&D obligations. The number of other institutions receiving $100,000 or more in obligations was about 400 in both 1994 and 1997. The non-research and non-doctorate-granting institutions also received a larger share of the reported Federal obligations for R&D to universities and colleges in the 1990s than they have at any time in the past—about 13 percent between 1993 and 1997. The largest percentage this group had received before the 1990s was just under 11 percent in 1977. This increase in share is consistent

[16]See chapter 4 sidebar, "Carnegie Classification of Institutions" for a brief description of the Carnegie categories.

Figure 6-9.
Number of academic institutions receiving Federal R&D support by selected Carnegie classification: 1971–97



NOTES: See "Carnegie Classification of Institutions" in Chapter 4 for information on the institutional categories used by the Carnegie Foundation for the Advancement of Teaching. "Other Carnegie institutions" are all institutions except Carnegie research and doctorate-granting institutions.

See appendix table 6-12. *Science & Engineering Indicators – 2000*

with the increase in the share of academic R&D support going to institutions below the top 100 reported in the earlier section on "Distribution of R&D Funds Across Academic Institutions."

EPSCoR—the Experimental Program to Stimulate Competitive Research

EPSCoR, the Experimental Program to Stimulate Competitive Research, is based on the premise that universities and their science and engineering faculty and students are valuable resources that can potentially influence a state's development in the 21st century much in the same way that agricultural, industrial, and natural resources did in the 20th century.

EPSCoR originated as a response to a number of stated Federal objectives. Section 3(e) of the National Science Foundation (NSF) Act of 1950, as amended, states that "it shall be an objective of the Foundation to strengthen research and education in the sciences and engineering, including independent research by individuals, throughout the United States, and to avoid undue concentration of such research and education." Even earlier, the 1947 Steelman report, *Science and Public Policy*, in discussing the formation of NSF, stated "*it is clear that a portion of the funds expended by the National Science Foundation should be used to strengthen the weaker, but promising, colleges and universities, and thus to increase our total scientific potential*." [Emphasis added]

But EPSCoR did not officially begin at NSF until 1978, when Congress authorized NSF to conduct EPSCoR in response to broad public concerns about the extent of geographical concentration of Federal funding of R&D. Eligibility for EPSCoR participation was limited to those jurisdictions that have historically received lesser amounts of Federal R&D funding and have demonstrated a commitment to develop their research bases and to improve the quality of science and engineering research conducted at their universities and colleges.

Eighteen states and the Commonwealth of Puerto Rico currently participate in the NSF program. The states are Alabama, Arkansas, Idaho, Kansas, Kentucky, Louisiana, Maine, Mississippi, Montana, Nebraska, Nevada, North Dakota, Oklahoma, South Carolina, South Dakota, Vermont, West Virginia, and Wyoming. As part of EPSCoR, NSF actively cooperates with state leaders in government, higher education, and business to establish productive long-term partnerships capable of effecting lasting improvements to the state's academic research infrastructure and increased national R&D competitiveness.

EPSCor increases the R&D competitiveness of an eligible state through the development and utilization of the science and technology resources residing in its major research universities. It achieves its objective by (1) stimulating sustainable science and technology infrastructure improvements at the state and institutional levels that significantly increase the ability of EPSCoR researchers to compete for Federal and private sector R&D funding, and (2) accelerating the movement of EPSCoR researchers and institutions into the mainstream of Federal and private sector R&D support.

Since 1979, other Federal agencies have adopted their own EPSCoR or EPSCoR-like programs with goals similar to those of NSF. In Fiscal Year 1993, Congressional direction precipitated the formation of the EPSCoR Interagency Coordinating Committee (EICC). A Memorandum of Understanding (MOU) was signed by officials of those agencies with EPSCoR or EPSCoR-like programs agreeing to participate in the EICC. The major objective of the MOU focused on improving coordination among and between the Federal agencies in implementing EPSCoR and EPSCoR-like programs consistent with the policies of participating agencies. The agencies included: DOD, DOE, the Environmental Protection Agency (EPA), NASA, NIH, NSF, and USDA. They agreed to the following objectives:

- Coordinate Federal EPSCoR and EPSCoR-like programs to maximize the impact of Federal support while eliminating duplication in states receiving EPSCoR support from more than one agency.
- Coordinate agency objectives with state and institutional goals, where appropriate, to obtain continued non-Federal support of S&T research and training.
- Coordinate the development of criteria to assess gains in academic research quality and competitiveness and in S&T human resource development.

In 1998, the seven EICC agencies spent a total of $89 million on EPSCoR or EPSCoR-like programs, up from $82 million in 1995. (See text table 6-1.)

Text table 6-1.
EPSCoR and EPSCorR-like program budgets, by agency
(Millions of dollars)

Agency	Fiscal year 1995	1996	1997	1998	1999[a]
Total	82.0	79.1	81.7	88.5	109.7
Department of Agriculture	13.6	11.1	11.0	13.6	13.0
Department of Defense	20.0	18.6	17.0	18.0	19.0
Department of Energy	6.1	6.5	6.3	6.4	6.8
Environmental Protection Agency	1.0		2.5	2.5	2.5
National Aeronautics and Space Administration	5.0	5.0	4.6	4.6	10.0
National Institutes of Health	0.9	2.2	1.9	5.0	10.0
National Science Foundation	35.4	35.7	38.4	38.4	48.4

EPSCoR = Experimental Program to Stimulate Competitive Research

[a]Figures for 1999 are estimates or authorized amounts.

SOURCES: "EPSCoR Interagency Coordinating Committee: FY 1999," unpublished report; and selected members of the EPSCoR Interagency Coordinating Committee.

Science & Engineering Indicators – 2000

Academic R&D Facilities and Equipment[17]

Physical infrastructure for academic R&D, especially the state of research facilities and equipment and levels and sources of funding for these two key components, remains a serious concern today.

Facilities[18]

Total Space. The amount of academic S&E research space has grown continuously over the decade. Between 1988 and 1998, total academic science and engineering research space increased by almost 28 percent, from about 112 million to 143 million net assignable square feet (NASF).[19] (See appendix table 6-13.) Doctorate-granting institutions account for most of the growth in research space over this period.

There was little change in the distribution of academic research space across fields of science and engineering between 1988 and 1998. (See appendix table 6-13.) About 90 percent of current academic research space continues to be concentrated in six S&E fields:

- the biological sciences (21 percent in 1988 and 22 percent in 1998),
- the medical sciences (17 percent in both years),
- engineering (from 14 to 16 percent),
- the agricultural sciences (from 16 to 17 percent),
- the physical sciences (from 14 to 13 percent), and
- the environmental sciences (6 percent in both years).

New Construction. The total cost of new construction projects has fluctuated over time. New construction projects begun in 1996 and 1997 for academic research facilities are expected to cost $3.1 billion. (See appendix table 6-14.) New construction projects initiated between 1986 and 1997 were expected to produce over 63 million square feet of research space when completed—the equivalent of about 45 percent of estimated 1998 research space. A significant portion of newly created research space is likely to replace obsolete or inadequate space rather than actually increase existing space. This is indicated by the fact that the total amount of research space increased by 31 million NASF between 1988 and 1998, a period in which new construction activity was expected to produce almost 54 million NASF. (See appendix table 6-13.) Thirty percent of all research-performing colleges and universities started new construction projects during 1996–97.

Science and Public Policy (Steelman report)
Part One—Science for the Nation, I.
Science and the National Interest

6. That a program of Federal assistance to universities and colleges be developed in the matters of laboratory facilities and scientific equipment as an integral part of a general program of aid to education. (Steelman 1947, p. 6.)

Part One—Science for the Nation, IV.
A National Science Program

The Need for New Facilities

A national research and development program of the size we require will necessitate a considerable expansion of research facilities. The extent and nature of this expansion cannot now be estimated, for the precise problems upon which we shall be engaged a few years from now cannot even be imagined today. Nor is it possible to determine, in view of the number of mixed-purpose facilities involved and the diversity of accounting methods, just what our present investment in such facilities may be. But we can make some informed guesses on this score as a bench-mark for the future.

The situation respecting the expansion of college and university facilities is altogether different. Existing facilities are relatively less adequate here than elsewhere and require substantial expansion. Additional libraries, laboratory space and equipment are urgently needed, not only in terms of the contemplated program of basic research, but to train scientists for research and development programs in the near future. Provision must, therefore, be made for Federal aid to educational institutions for the construction of facilities and the purchase of expensive equipment. A beginning was made on this in connection with the disposal of surplus property. It must now be put on a long-run basis.

Any such program for federally-financed research facilities should be part of a broader program of aid to higher education. In many cases, the expansion of laboratories is possible only if other expansions in plant occur. The whole problem of university and college facilities is a broad and integrated one and should be handled as such. (Steelman 1947, 36.)

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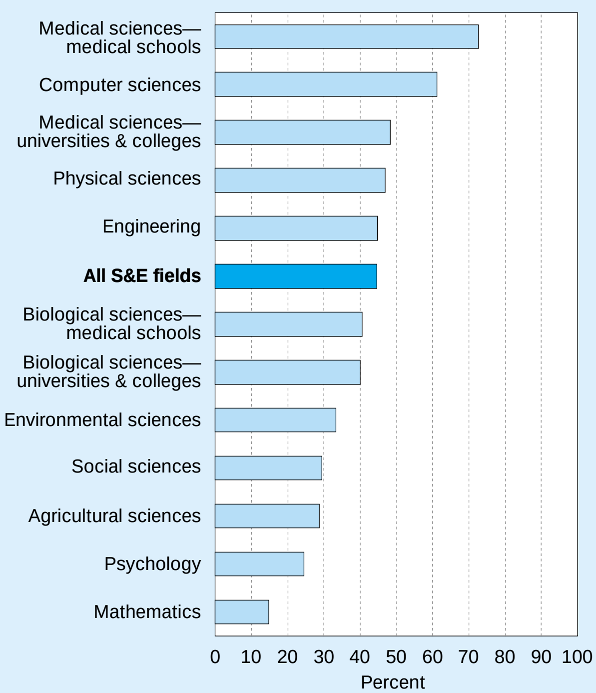
[17]Data on facilities and equipment are taken primarily from several surveys supported by NSF. Although terms are defined specifically in each survey, in general facilities expenditures (1) are classified as "capital" funds, (2) are fixed items such as buildings, (3) often cost millions of dollars, and (4) are not included within R&D expenditures as reported here. Equipment and instruments (the terms are used interchangeably) are generally movable, purchased with current funds, and included within R&D expenditures. Because the categories are not mutually exclusive, some large instrument systems could be classified as either facilities or equipment.

[18]The information in this section is derived from NSF's biennial Survey of Scientific and Engineering Research Facilities at Colleges and Universities. For more detailed data and analysis on academic S&E research facilities (for example, by institution type and control), see NSF (2000b).

[19]"Research space" here refers to the net assignable square footage (NASF) of space within facilities (buildings) in which S&E research activities take place. NASF is defined as the sum of all areas (in square feet) on all floors of a building assigned to, or available to be assigned to, an occupant for specific use, such as instruction or research. Multipurpose space within facilities, such as an office, is prorated to reflect the proportion of use devoted to research activities. NASF data for new construction and repair/renovation are reported for combined years (for example, 1987–88 data are for fiscal years 1987 and 1988). NASF data on total space are reported at the time of the survey and were not collected in 1986.

The ratio of planned new construction during the 1986–97 period to 1998 research space differs across S&E fields. More than half of the research space in the medical sciences at medical schools and in the computer sciences appears to have been built in the 1986–97 period. In contrast, less than 20 percent of the research space for mathematics appears to have been newly constructed during this period. (See figure 6-10.)

Figure 6-10.
Planned new construction between 1986 and 1997 as a percentage of 1998 research space, by S&E field



See appendix table 6-13. *Science & Engineering Indicators – 2000*

Repair and Renovation. The total cost of repair/renovation projects has also fluctuated over time. Expenditures for major repair/renovation (that is, projects costing over $100,000) of academic research facilities begun in 1996–97 are expected to reach $1.3 billion. (See appendix table 6-14.) Projects initiated between 1986 and 1997 were expected to result in the repair/renovation of almost 71 million square feet of research space.[20] (See appendix table 6-13.) Repair/renovation expenditures as a proportion of total capital expenditures (construction and repair/renovation) have increased steadily since 1990–91, rising from 22 percent of all capital project spending to 30 percent by 1996–97. More than half (52 percent) of all research-performing colleges and universities started new repair/renovation projects during 1996–97.

Sources of Funds. Academic institutions derive their funds for new construction and repair/renovation of research facilities from three major sources: institutional resources, state and local governments, and the Federal Government. Institutional resources consist of private donations, institutional funds, tax-exempt bonds, other debt sources, and other sources. (See text table 6-2.) In 1996–97:

- institutional resources accounted for 60 percent of all construction funds and 65 percent of all repair/renovation funds;
- state and local governments accounted for 31 percent of all construction funds and 26 percent of all repair/renovation funds; and
- the Federal Government directly accounted for only 9 percent of all construction funds and 9 percent of all repair/renovation funds.[21]

Public and private institutions draw upon substantially different sources to fund the construction and repair/renovation of research space. The relative distribution of construction funds between institutional types is as follows:

- Institutional resources accounted for 43 percent of all construction funds at public institutions and 91 percent at private institutions.
- State and local governments accounted for 47 percent of all construction funds at public institutions and 2 percent at private institutions.
- The Federal Government accounted for 10 percent of all construction funds at public institutions and 6 percent at private institutions.

The relative distribution of repair/renovation funds between institution types is as follows:

- Institutional resources accounted for 40 percent of all repair/renovation funds at public institutions and 91 percent at private institutions.
- State and local governments accounted for 49 percent of all repair/renovation funds at public institutions and 2 percent at private institutions.
- The Federal Government accounted for 11 percent of all repair/renovation funds at public institutions and 7 percent at private institutions.

Adequacy and Condition. Of those institutions reporting research space in a field, at least half reported inadequate amounts of space in every identifiable S&E field except math-

[20]It is difficult to report repaired/renovated space in terms of a percentage of existing research space. As collected, the data do not differentiate between repair and renovation, nor do they provide an actual count of unique square footage that has been repaired or renovated. Thus, any proportional presentation might include double or triple counts, since the same space could be repaired (especially) or renovated several times.

[21]Some additional Federal funding comes through overhead on grants and/or contracts from the Federal Government. These indirect cost payments are used to defray the overhead costs of conducting federally funded research and are counted as institutional funding. A recent memo (Jankowski 1999) indicates that about 6 to 7 percent of indirect cost payments are a reimbursement for depreciation and use of R&D facilities and equipment.

ematics, where 44 percent of the institutions reporting indicated that the amount of research space was inadequate.[22] (See text table 6-3.) In some S&E fields, a larger percentage of academic institutions rate their research space as inadequate than in others. At least 60 percent of all institutions reported that their research space was inadequate in each of the following seven S&E fields: the biological sciences in medical schools (70 percent); the medical sciences in medical schools (67 percent); the biological sciences outside of medical schools (64 percent); the physical sciences (64 percent); the earth, atmospheric, and ocean sciences (62 percent); the social sciences (61 percent); and engineering (60 percent).

[22]Adequate space is defined as the space in the field being sufficient to support all the needs of the current S&E research program commitments in the field. Inadequate amount of space is defined as space in the field insufficient to support the needs of the current S&E research program commitments in the field or nonexistent but needed.

Text table 6-2.
Funds for new construction and repair/renovation of S&E research space, by type of institution and funding source: 1996–97
(Millions of dollars)

Institution type and funding source	New construction and repair/renovation	New construction	Repair/ renovation
Total, all institutions	4,435	3,110	1,325
Federal Government	392	271	121
State and local government	1,305	967	338
Institutional sources	2,739	1,873	866
Total, public institutions	2,657	1,988	669
Federal Government	273	201	72
State and local government	1,268	940	328
Institutional sources	1,116	847	269
Total, private institutions	1,776	1,121	655
Federal Government	118	70	48
State and local government	36	26	10
Institutional sources	1,622	1,025	597

NOTE: Details may not add to totals because of rounding.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Scientific and Engineering Research Facilities at Universities and Colleges: 1998*, in press (Arlington, VA: 2000).

Science & Engineering Indicators – 2000

Text table 6-3.
Adequacy of the amount of S&E research space, by field: 1998

Field	Total number of institutions	Percentage of institutions reporting that their armount of space is: Adequate	Inadequate
Physical sciences	556	36	64
Mathematical sciences	416	56	44
Computer sciences	395	44	56
Environmental sciences	365	38	62
Agricultural sciences	108	45	55
Biological sciences—universities and colleges	569	36	64
Biological sciences—medical schools	127	30	70
Medical sciences—universities and colleges	280	46	54
Medical sciences—medical schools	127	33	67
Psychology	474	49	51
Social sciences	428	39	61
Other sciences	149	56	44
Engineering	290	40	60

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Scientific and Engineering Research Facilities at Universities and Colleges: 1998,* in press (Arlington, VA: 2000).

Science & Engineering Indicators – 2000

Survey respondents are asked to rate the condition of their space. Almost 40 percent of S&E research space was rated as "suitable for the most scientifically competitive research." However, 18 percent of the research space was designated as needing major repair/renovation, and an additional 5 percent as needing replacement. The condition of this space differs across S&E fields. Fields with the greatest area of research space needing major repair/renovation or replacement include: the agricultural sciences (7.5 million NASF); the biological sciences outside medical schools (4.8 million NASF); the medical sciences in medical schools (4.6 million NASF); engineering (4.3 million NASF); and the physical sciences (3.9 million NASF). Fields with the largest proportion of research space needing major repair/renovation or replacement include the agricultural sciences (30 percent), and the environmental sciences, the biological sciences outside medical schools, the medical sciences in medical schools, and the medical sciences outside of medical schools (each with about 25 percent). (See text table 6-4 and appendix table 6-13.)

Unmet Needs. Determining what universities and colleges need with regard to S&E research space is a complex matter. In order to attempt to measure "real" as opposed to "speculative" needs, respondents to the survey were asked to report whether an approved institutional plan existed that included any deferred space needing new construction or repair/renovation.[23] Respondents were then asked to estimate, for each S&E field, the costs of such construction and repair/renovation projects and, separately, the costs for similar projects not included in an approved institutional plan.

In 1998, 54 percent of the institutions reported that they had to defer needed S&E construction or repair/renovation projects that would support their current research program commitments because of insufficient funds. The vast majority of institutions that had deferred projects (87 percent) had included at least some of these projects in an approved institutional plan. The total estimated cost for deferred S&E construction and repair/renovation projects (both in and not in an institutional plan) was $11.4 billion in 1998. Deferred construction projects accounted for 61 percent of this cost and deferred repair/renovation projects for the other 39 percent.

Deferred construction costs exceeded $1 billion in each of three fields. Institutions reported deferred repair/renovation costs in excess of $500 million in the same three fields. These fields and the deferred costs are: the physical sciences ($1.6 billion construction, $0.9 billion repair/renovation); the biological sciences outside medical schools ($1.2 billion construction, $0.9 billion repair/renovation); and engineering ($1.0 billion construction, $0.7 billion repair/renovation). (See appendix table 6-15.)

Equipment

Expenditures.[24] In 1997, just under $1.3 billion in current fund expenditures were spent for academic research equipment. About 80 percent of these expenditures were con-

[23]Four criteria are used to define deferred space in a survey cycle: (1) the space must be necessary to meet the critical needs of current faculty or programs, (2) construction must not have been scheduled to begin during the two fiscal years being covered by the survey, (3) construction must not have funding set aside for it, and (4) the space must not be for developing new programs or expanding the number of faculty.

[24]Data used here are from the NSF Survey of R&D Expenditures at Universities and Colleges; they are limited to current funds expenditures for research equipment and do not include funds for instructional equipment. Current funds—as opposed to capital funds—are those in the yearly operating budget for ongoing activities. Generally, academic institutions keep separate accounts for current and capital funds.

Text table 6-4.
Condition of academic science and engineering research facilities by field: 1998
(Percentages of S&E research space)

Field	Suitable for use in most scientifically sophisticated research	Requires limited repair/renovation to be used effectively	Requires major repair/renovation to be used effectively	Requires replacement
All science & engineering	39.0	38.0	18.0	5.0
Physical sciences	36.2	42.3	16.5	4.9
Mathematical sciences	44.3	41.4	11.5	2.9
Computer sciences	44.1	40.0	10.8	5.0
Environmental sciences	33.5	41.0	17.5	8.0
Agricultural sciences	32.9	36.8	23.8	6.5
Biological sciences—universities and colleges	39.6	35.5	19.6	5.3
Biological sciences—medical schools	49.3	34.6	14.1	2.0
Medical sciences—universities and colleges	31.7	43.0	20.9	4.4
Medical sciences—medical schools	43.2	31.4	19.9	5.6
Psychology	40.5	41.0	16.3	2.2
Social sciences	38.8	45.2	14.5	1.5
Engineering	41.2	39.9	14.9	3.9

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Scientific and Engineering Research Facilities at Universities and Colleges: 1998*, in press (Arlington, VA: 2000).

Science & Engineering Indicators – 2000

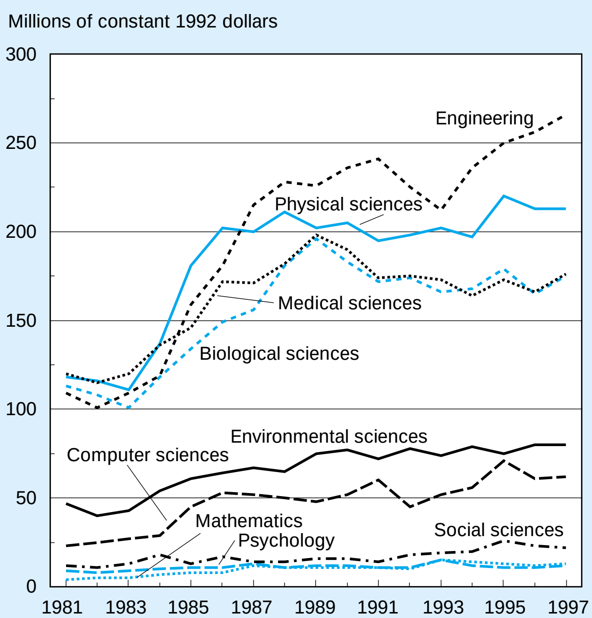
centrated in three fields: the life sciences (37 percent), engineering (23 percent), and the physical sciences (19 percent). (See figure 6-11.)

Current fund expenditures for academic research equipment grew at an average annual rate of 3.8 percent (in constant 1992 dollars) between 1981 and 1997. However, average annual growth was much higher during the 1980s (6.2 percent) than it was during the 1990s (0.7 percent). There were variations in growth patterns during this period among S&E fields. For example, equipment expenditures for mathematics (7.8 percent), the computer sciences (6.4 percent), and engineering (5.7 percent) grew more rapidly during the 1981–97 period than did those for the life sciences (2.2 percent) and psychology (2 percent). (See appendix table 6-16.)

Federal Funding. Federal funds for research equipment are generally received either as part of research grants—thus enabling the research to be performed—or as separate equipment grants, depending on the funding policies of the particular Federal agencies involved. The importance of Federal funding for research equipment varies by field. In 1997, the social sciences received slightly less than 40 percent of their research equipment funds from the Federal Government; in contrast, Federal support accounted for over 60 percent of equipment funding in the physical sciences, computer sciences, environmental sciences, and psychology.

The share of research equipment expenditures funded by the Federal Government declined from 63 percent to 59 percent between 1981 and 1997, although not steadily. This overall pattern masks different trends in individual S&E fields. For example, the share funded by the Federal Government actually rose during this period for both the computer and the environmental sciences. (See appendix table 6-17.)

Figure 6-11.
Current fund expenditures for research equipment at academic institutions, by field: 1981–97



NOTE: See appendix table 2-1 for GDP implicit price deflators used to convert current dollars to constant 1992 dollars.

See appendix table 6-16. *Science & Engineering Indicators – 2000*

R&D Equipment Intensity. R&D equipment intensity is the percentage of total annual R&D expenditures from current funds devoted to research equipment. This proportion was lower in 1997 (5 percent) than it was in 1981 (6 percent) and at its peak in 1986 (7 percent). (See appendix table 6-18.) R&D equipment intensity varies across S&E fields. It tends to be higher in the physical sciences and the computer sciences (both about 10 percent in 1997) and engineering (8 percent); and lower in the social sciences (2 percent), psychology (3 percent), and the life sciences (4 percent). For the social sciences and psychology, these differences may reflect the use of less equipment and/or less expensive equipment. For the life sciences, the lower R&D equipment intensity is more likely to reflect use of equipment that is too expensive to be purchased out of current funds and therefore must be purchased using capital funds. (See footnote 24.)

Academic Doctoral Scientists and Engineers

This section examines major trends over the 1973–97 period regarding the composition of the academic science and engineering (S&E) workforce, its primary activities (teaching vis-à-vis research), and the extent of its support by the Federal Government. For a discussion of the nature of the data used here, see sidebar, "Data Source."

The Academic Doctoral Science and Engineering Workforce[25]

Employment of science and engineering doctorates exceeded 60,000 by 1961[26] and reached 215,000 by 1973. Since 1973, the number has more than doubled, reaching 505,200 in 1997—a 135 percent increase. (See chapter 3, "Science and Engineering Workforce.") Over the 1973–97 period, the academic employment component increased from an estimated 118,000 to 232,500—a rise of 97 percent.[27] (See appendix table 6-19.) Consequently, the academic employment share declined over the period from an estimated 55 percent

[25]The academic doctoral science and engineering workforce includes full, associate, and assistant professors and instructors—defined throughout this section as faculty—lecturers, adjunct faculty, research and teaching associates, administrators, and postdoctorates.

[26]NSF (1964).

[27]The trend data in this section refer to scientists and engineers with doctorates from U.S. institutions, regardless of their citizenship status. Comparable long-term trend data for Ph.D.-level scientists and engineers with degrees from non-U.S. institutions are not available. A 1993 U.S. Department of Education survey of academic faculty suggests that this component of the academic workforce numbers around 13,000. An estimate derived from NSF's National Survey of College Graduates, based on the 1990 Census, puts the number at about 21,000. The higher estimate (which includes postdoctorates not necessarily covered by the Department of Education's survey) is likely to more closely reflect the definitions used in this chapter.

Data Source

The data used in this section to describe the employment characteristics and activities of academic doctoral scientists and engineers derive from the biennial sample Survey of Doctorate Recipients (SDR). SDR has been conducted since 1973 under the sponsorship of the National Science Foundation and several other Federal agencies. It underwent several changes in 1991 and again from 1993 forward which affect the comparability of data from these years with those of earlier periods.

Through 1989, the sample included three major respondent segments: (1) recipients of S&E doctorates from U.S. institutions; (2) a small number of holders of doctorates in other fields working in science or engineering in the survey year; and (3) a small number of persons with S&E doctorates from non-U.S. institutions. Starting with the 1991 sample, only recipients of S&E doctorates from U.S. universities were retained, and persons over 75 years old were ruled out of scope. Furthermore, sampling strata and sample size were reduced in an effort to improve response rates within budget constraints. Other changes in data collection included the introduction of computer-assisted telephone interviewing, which resulted in much higher response rates than had been attained previously.

A 31-month interval between the 1989 and 1991 surveys, instead of the usual 24 months, had substantive effects on the 1991 data: for example, a lower-than-average proportion of respondents in postdoctoral status, a higher-than-average proportion in faculty ranks. The interval between the 1991 and 1993 surveys was also nonstandard, 20 months.

Methodological studies to assess the full impact of these changes on overall estimates and individual data items are unavailable. Preliminary investigations suggest that SDR data permit analysis of rough trends, provided comparisons are limited to recipients of S&E doctorates from U.S. institutions. This has been done herein, with data structured in accordance with suggestions offered by the National Research Council's Office of Scientific and Engineering Personnel, which conducted these surveys through 1995. Nevertheless, the reader is warned that small statistical differences should be treated with caution.

The academic doctoral science and engineering workforce discussed in this chapter includes full, associate, and assistant professors and instructors—defined throughout this section as faculty—lecturers, adjunct faculty, research and teaching associates, administrators, and postdoctorates. Any discussion herein of status or trends of particular fields is based on the field of doctorate.

in 1973 to 46 percent of the doctoral science and engineering workforce in the 1990s, where it remains—close to its 1945–47 level.

Growth in academic employment over the past half century reflected both the need for teachers, driven by increasing enrollments, and an expanding research function, largely supported by Federal funds. The resulting relationship in academia of teaching and research, and the balance between them, remains the subject of intense concern and discussion[28] at the national level, as well as in academic institutions. Trends in indicators relating to research funding have been presented above. Below follow indicators reflecting the personnel dimension of these discussions: the relative balance between faculty and nonfaculty positions; demographic composition of the faculty; faculty age structure and hiring of new Ph.D.s; and trends in work responsibilities as reported by S&E Ph.D.s employed in academia.

[28]Some examples include *Presidential Directive for the Review of the Federal Government-University Partnership* (National Science and Technology Council 1999); *Challenges to Research Universities* (Noll 1998); "The American Academic Profession" (*Daedalus* 1997); *Science in the National Interest* (Clinton and Gore 1994); *Stresses on Research and Education at Colleges and Universities* (National Academy of Sciences 1994); *Renewing the Promise: Research-Intensive Universities and the Nation* (President's Council of Advisors on Science and Technology 1992); *Science and Technology in the Academic Enterprise: Status, Trends, and Issues* (National Academy of Sciences 1989); *Report of the White House Science Council: Panel on the Health of U.S. Colleges and Universities* (U.S. Office of Science and Technology Policy 1986).

A Long-Term Shift Toward Nonfaculty Employment Continued During the 1990s

Academic employment growth of science and engineering doctorates was quite low during much of the 1990s, from an estimated 206,700 in 1989 to 217,500 in 1995—an average annual increase of less than 1 percent. But by 1997, it had reached 232,500, reflecting a much stronger average rate of increase—3.4 percent annually—reminiscent of the growth rates registered during the 1980s. (See figure 6-12 and appendix table 6-19.)

Full-time doctoral S&E faculty—full, associate, and assistant professors plus instructors—participated in the 1995–97 increase. Their number, which had been roughly stable during the first half of the 1990s, rose strongly from 171,400 in 1995 to 178,400 in 1997. (See figure 6-12.) Nevertheless, the share of full-time faculty among all doctoral scientists and engineers with academic employment continued to decline. It reached an all-time low of 77 percent in 1997, from 88 percent in 1973; and 82 percent in 1989. (See appendix table 6-19.)

Thus, a long-term shift toward nonfaculty employment continued, as those in nonfaculty ranks—adjunct faculty, lecturers, research and teaching associates, administrators, and postdoctorates—increased from 36,900 in 1989 to 54,200 in 1997. The 47 percent increase for this group stood in sharp contrast to the 5 percent rise in the number of full-time faculty. Much of the rise in the nonfaculty segment was due to

Science and Public Policy (Steelman report)
Part One—Science for the Nation, III. Manpower: The Limiting Resource

Under present conditions, the ceiling on research and development activities is fixed by the availability of trained personnel, rather than the amounts of money available. The limiting resource at the moment is manpower.

…Those actually engaged in scientific research, technical development, and teaching comprise a much smaller group within this pool—about 137,000 persons today....But just as the share of the universities and colleges in the national research budget has been falling since 1930, so has their share in the trained manpower pool: from about 49 percent in 1930 to 41 percent in 1940 and 36 percent in 1947.

This is significant, because college and university scientists not only perform the major portion of basic research, but also because they teach. They are the source of further expansion in our pool of trained manpower. [Boldface in original]

There is a still smaller group within the 137,000 working scientists of which note should be taken: the 25,000 highly trained scientists with doctorates in the physical and biological sciences. As a general proposition,…[their number] provides a measure of the size of the group on which we rely for leadership in research, and for advanced teaching in the sciences.

[The table below, reproduced from volume four, shows the estimated distribution of doctoral scientists by sector for 1937–47.]

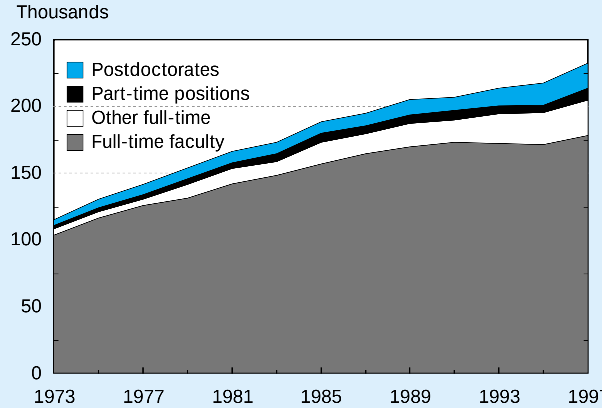
Year	Total	Colleges and universities	Industry	Government
1937	13,900	8,100	4,300	1,500
1945	23,200	10,000	10,000	3,200
1947	24,500	13,000	9,000	2,500

(Steelman 1947, 15.)

the growing use of postdoctorates.[29] Part-time employment—including faculty and other positions—accounted for between 2 and 4 percent of the total throughout. (See figure 6-12 and appendix table 6-19.)

This substantial shift during the 1990s toward nonfaculty employment touched most major fields. Except for computer sciences, continued growth in the nonfaculty segment was the rule. By 1997, full-time faculty percentages had dropped by as many as 10 percentage points (environmental sciences) since 1989 alone, with the other fields' declines falling into the 4–7 percentage points range. Over the entire period—1973 to 1997—the drops in the faculty share by field ranged from 8 to 18 percent. From 1989 to 1997, gains in the number of full-time faculty were largely confined to Ph.D.s in the life and computer sciences. For all other fields, their number remained essentially unchanged. (See appendix table 6-19.)

Figure 6-12.
Academic doctoral scientists and engineers by type of position: 1973–97



NOTE: Faculty includes full, associate and assistant professors plus instructors.

SOURCE: National Science Foundation, Division of Science Resources Studies, Survey of Doctorate Recipients, special tabulation.

See appendix table 6-19. *Science & Engineering Indicators – 2000*

Research Universities' Employment Grew More Slowly Than That of Other Academic Institutions

The Nation's largest research-performing universities—Carnegie Research I and II institutions[30]—are widely regarded as a vital resource in U.S. science and engineering research and teaching. The number of doctoral scientists and engineers they employ rose steadily after 1973 but has essentially been static since 1989, at an estimated 113,600 in 1997. (See appendix table 6-20.) In contrast, employment at other institutions has grown uninterruptedly, especially after 1995. Since 1989, the research universities experienced a 6 percent decline in the number of their full-time doctoral S&E faculty, which was roughly offset by a 24 percent increase in nonfaculty personnel. Over the same period, other institutions' doctoral S&E employment expanded by 26 percent, with faculty rising by 7 percent and nonfaculty appointments more than doubling.

Behind these trends lie very different hiring patterns practiced by these institutions, as illustrated by an examination of their hiring of cohorts of recent doctorates—defined as those with a doctorate awarded within the last three years. (See fig-

[29]For more information on this subject, see "Postdoctoral Appointments" in chapters 3 and 4.

[30]Carnegie Classification Research I and II universities. This periodically revised classification describes research universities as institutions with a full range of baccalaureate programs, commitment to graduate education through the doctorate, annual award of at least 50 doctoral degrees, and receipt of Federal support of at least $15.5 million (average of 1989 to 1991). These criteria were met by 127 universities. (Carnegie Foundation for the Advancement of Teaching 1994).

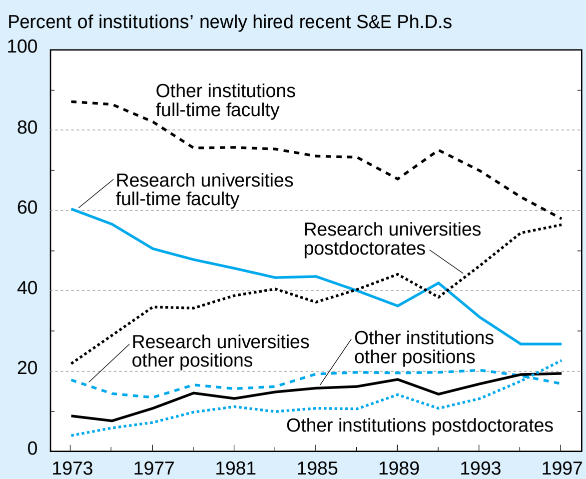
ure 6-13 and appendix table 6-21.) Except for the early 1970s, the research universities have consistently hired more recent Ph.D.s than all other universities and colleges combined. But their hiring has slowed in the 1990s, while that of the other institutions has increased. More telling is the distribution of these new hires by type of appointment. In recent years, fewer than 30 percent of recent doctorates hired by the research universities obtained a full-time faculty position—down from 60 percent in 1973. In contrast, almost 60 percent of those hired by other academic institutions received faculty appointments (compared to nearly 90 percent in 1973).

In the research universities, employment growth of S&E doctorates has largely been driven by those identifying research as their primary activity. (See appendix table 6-20.) Their number, 22,900 in 1973, had risen to an estimated 60,700 by 1997; their percentage among the research universities' doctoral S&E workforce rose from 35 to 53 percent. In contrast, the number of those for whom teaching was the primary activity rose from 32,300 in 1973 to a high of 39,200 in 1981 before declining to 33,400 in 1997—a decline from 50 to 29 percent of the total. Those identifying other functions as their primary work responsibility—including research management—grew from 9,200 to 19,600 over the period—staying well below 20 percent of the total for virtually the entire period.

In other types of universities and colleges, the number of doctoral scientists and engineers who identified research as their primary work activity grew from 4,900 in 1973 to 27,900 in 1997. Their share over the period rose from 9 to 23 percent, steeply increasing from the mid-1980s onward. The number of those for whom teaching was the primary work responsibility increased less rapidly, from 41,000 in 1973 to 72,000 in 1997. (See appendix table 6-20.)

Employment patterns also differed among full-time doctoral S&E faculty. At the research universities, full-time faculty overall fell by 6 percent between 1989 and 1997, with those reporting primary responsibility for research declining by 3 percent, and those with primary teaching responsibility by 9 percent. Developments were different in the other institutions, where full-time faculty rose by 7 percent over the same period, largely reflecting an increase of 4,300—40 percent—among those with primary research responsibility.

Figure 6-13.
Recent S&E Ph.D.s hired by research universities and other academic institutions, by type of institution and appointment: 1973–97



NOTES: Recent Ph.D.s have earned their doctorates in the three years preceding the survey year. Faculty includes full, associate, and assistant professors plus instructors. "Other positions" include part-time, research associate, adjunct, and other types of appointments outside the faculty track. Research universities are Carnegie Research I and II institutions.

SOURCE: National Science Foundation, Division of Science Resources Studies, Survey of Doctorate Recipients, special tabulations.

See appendix table 6-21. *Science & Engineering Indicators – 2000*

Women Are Increasingly Prominent in Academic S&E, but Not in All Fields[31]

The academic employment of women with a doctorate in science or engineering has risen dramatically over the past quarter century, reflecting the steady increase in the proportion of S&E doctorates earned by women. Since 1973, when this type of employment information was first collected, the number of women has increased more than fivefold, from 10,700 to an estimated 59,200 in 1997. Their proportion of the doctoral academic S&E workforce has increased from 9 to 25 percent over the period. (See appendix table 6-22.)

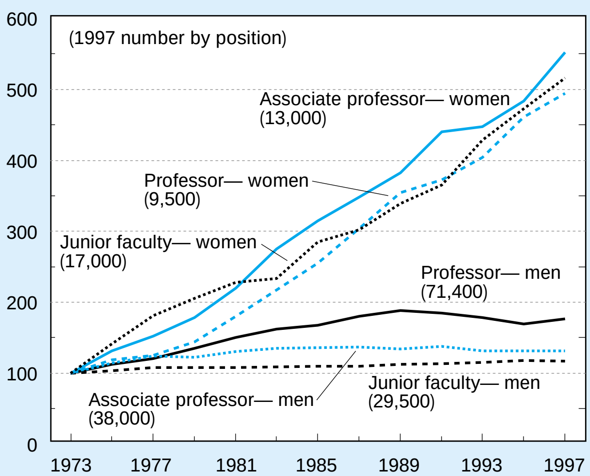
A similar rapid growth was registered in the number of women in full-time faculty positions.[32] (See figure 6-14.) However, even with this strong growth, their proportion of full-time faculty continues to lag their share of Ph.D. degrees. This underscores the long time lag involved in changing the composition of a large employment pool—in this instance, the academic faculty. Women represented 7 percent of the full-time doctoral academic S&E faculty in 1973. The effect of a growing proportion of doctorates earned by women, bolstered by their somewhat greater likelihood of choosing early academic careers, had pushed this proportion to 22 percent by 1997. By rank, they represented 12 percent of full professors, 25 percent of associate professors, and 37 percent of the junior faculty—the latter approximately in line with their recent share of Ph.D.s earned. (See appendix table 6-22.)

Among full-time doctoral S&E faculty, the number of men declines as one moves from senior ranks—full and associate professors—to junior-faculty ranks—assistant professors and instructors. In contrast, the distribution of women is inverted: more women hold junior faculty positions than are associate professors, and more are the latter than are full professors. This pattern is indicative of the recent arrival of significant

[31]Also see "Women Scientists and Engineers" in chapter 3 and "New Ph.D.s Enter Academia, but the Nature of Their Appointments Has Changed" later in this chapter.

[32]These numbers differ from those published in *Women, Minorities, and Persons with Disabilities in Science and Engineering: 1998* (NSF 1999k). That report's tables 5-9 through 5-12 show data on employment in four-year colleges and universities only, excluding faculty in other types of academic institutions, such as medical schools, two-year colleges, and specialized colleges. All of the latter are included here.

Figure 6-14.
Index of growth in full-time doctoral science and engineering faculty, by rank and sex: 1973–97



NOTES: Junior faculty includes assistant professors and instructors. Postdoctorate, nonfaculty, and part-time positions are not shown.

See appendix table 6-22. *Science & Engineering Indicators – 2000*

numbers of women doctorates in full-time academic faculty positions. It indicates that the trend toward increasing numbers of women among the faculty will continue—assuming that women stay in academic positions at an equal or higher rate than men—but also, that this process will continue to unfold slowly.

Since 1973, when these data on doctoral scientists and engineers were first collected, women in academic employment have been heavily concentrated in a few fields. Fully 84 percent of women scientists and engineers in 1997 had earned their doctorates in three broad fields: life sciences (42 percent), social sciences (22 percent), and psychology (20 percent); in contrast, only 58 percent of men were in these fields in 1997. Conversely, only 9 percent of women had degrees in the physical and environmental sciences in 1997—a steep decline from 14 percent of women in these fields in 1973—compared to 19 percent of men. Only 3 percent of all women had doctorates in engineering, versus 14 percent of men. (See appendix table 6-22.)

Concentration notwithstanding, when viewed over the entire 1973–97 period, women's doctoral field choices have undergone some changes. Among the academically employed, smaller proportions were found to hold doctorates in the physical and environmental sciences and mathematics in 1997 than in the early 1970s; these fields experienced a combined drop from 20 to 12 percent. Women's 37 percent life sciences share in 1973 rose to 42 percent in 1997, and larger percentages of women were also found with a Ph.D. in engineering and computer science by 1997. However, the proportion of women in academic employment with degrees in these latter fields remains very low. (See appendix table 6-22.)

Minorities See Large Growth Rates in Ph.D.s in Academic Employment, but Low Absolute Numbers[33]

The U.S. Bureau of the Census's demographic projections have long indicated an increasing prominence of minority groups among future college and working-age populations. With the exception of Asians and Pacific Islanders—who have been quite successful in earning science and engineering doctorates—these groups have tended to be less likely than the majority population to earn S&E degrees or work in S&E occupations. Private and governmental activities seek to broaden the opportunities of American Indians, Alaskan Natives, blacks, and Hispanics to enter these fields. Many target advanced scientific, engineering, and mathematics training, including doctoral-level work. What are the trends and status of these minority groups among S&E Ph.D.s employed in academia?

The story for these doctoral-level scientists and engineers is one of two trends, one dealing with rates of increase in hiring, the second with the slowly changing composition of the academic workforce. Rates of increase in employment have been remarkably steep. (See figure 6-15.) They far outpaced those for the majority population and have generally reflected the increased earning of science and engineering doctorates by minority group members.[34] However, a signal feature of these steep increases is the low bases from which they are calculated. As a result of the large majority population in the initial academic S&E doctoral pool,[35] American Indians, Alaskan Natives, blacks, and Hispanics remain a small minority in academia. Changing the structure of a large employment pool by changing the composition of the new participants requires a long time, unless the size of the inflow relative to the existing pool is large. (See appendix table 6-23.)

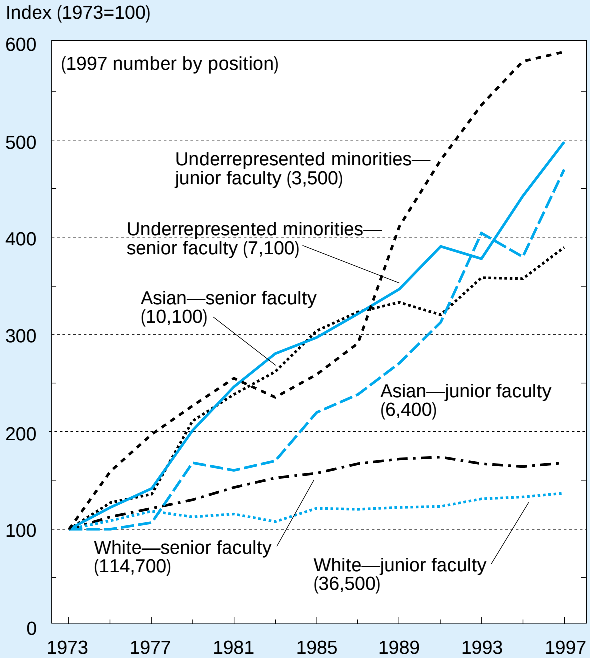
Academic employment of underrepresented minorities with S&E doctorates—American Indians, Alaskan Natives, blacks, and Hispanics—rose to 13,700 in 1997 from a mere 2,400 in 1973. Over this period, their employment share rose from 2 to 6 percent, approximately the same as their share of full-time faculty positions. By 1997, underrepresented minorities represented about 8 percent of the academic doctoral employment of those with degrees in psychology and the social sciences, 5–6 percent in the physical and life sciences, mathematics, and engineering, but only 3 percent in computer and environmental sciences. Their faculty percentages were quite similar. (See appendix table 6-23.) The overall field distribution of underrepresented minorities broadly parallels that of the majority population, with two exceptions. In 1997, underrepresented minorities were distinctly *less* likely than whites to possess Ph.D.s in the life sciences—

[33]Also see "Racial or Ethnic Minority Scientists and Engineers" in chapter 3 and "New Ph.D.s Enter Academia, but the Nature of Their Appointments Has Changed" later in this chapter.

[34]This in turn, of course, reflects their increasing participation in higher education and graduate school training. See chapter 4 sections, "Master's Degrees, by Race/Ethnicity" and "Doctoral Degrees, by Race/Ethnicity."

[35]Here measured from 1973 onward; data covering longer periods are not readily available.

Figure 6-15.
Index of growth in full-time doctoral science and engineering faculty, by rank and race/ethnicity: 1973–97



NOTES: Senior faculty includes full and associate professor; junior faculty includes ranks of assistant professor and instructor. Underrepresented minorities include American Indians, Alaskan Natives, blacks, and Hispanics.

SOURCE: National Science Foundation, Division of Science Resources Studies, Survey of Doctorate Recipients, various years, special tabulations.

See appendix table 6-23. *Science & Engineering Indicators – 2000*

28 versus 34 percent—and *more* likely to hold social sciences doctorates—26 versus 20 percent.

Asians and Pacific Islanders as a group have been quite successful in entering the academic doctoral workforce in science and engineering, as their number rose from 5,000 in 1973 to 25,400 in 1997. As a consequence of this rapid growth, their employment share nearly tripled, from 4 to 11 percent since 1973. In 1997, Asians and Pacific Islanders represented 27 percent of academically employed computer science Ph.D.s, 20 percent of engineers, and 14 percent of physical scientists and mathematicians. Their academic employment share among environmental and social science Ph.D.s, and especially psychologists, remained low—7 percent for the two former fields, less than 3 percent in the latter.[36] (See appendix table 6-23.)

Asian and Pacific Islander S&E doctorates in academic employment were much more concentrated in a few fields than other population groups. In 1997, 51 percent held degrees in the physical, environmental, and computer sciences; mathematics; or engineering—a much higher proportion than for whites (34 percent) or underrepresented minorities (28 percent). In part, this reflects the degree-taking choices of temporary visa-holders, who tend to favor engineering and mathematics-based sciences over less quantitative fields, and who often remain in the United States and gain academic employment. They have constituted more than half of the Asian and Pacific Islanders' total during the 1990s.

The Physical Sciences' Employment Share Declined; Life Sciences' Increased

The field composition of science and engineering Ph.D.s in academic employment over the 1973–97 period has been remarkably stable, with two notable exceptions: The academic employment share of Ph.D.s in the physical sciences declined from 19 to 13 percent, while that of doctorates in the life sciences rose slightly from 30 to 33 percent. Employment growth of physical sciences doctorates—rising 37 percent from 22,100 to 30,200—was much slower than that of other fields, which grew by a combined 107 percent overall; similar discrepancies were evident for growth in the full-time faculty segment. Both physics and chemistry shared this slow growth trajectory. In contrast, employment of Ph.D.s in the life sciences increased by more than 120 percent over the period, rising from 34,900 to 77,300. A large share of this gain reflected increases in the nonfaculty segment.[37] (See appendix table 6-19.)

The Average Age of the Academic S&E Faculty Continues to Increase

The rapid pace of hiring of young Ph.D.s into academic faculty positions during the 1960s to accommodate soaring enrollments, combined with slower hiring in later years, has resulted in a continuing increase in the average age of the U.S professorate. (See figure 6-16.) In 1973, 62 percent of the doctoral, full-time S&E faculty were under 45 years old, and only 13 percent were 55 or older. The under-45 group had shrunk to 50 percent by 1985 and constituted only 38 percent of the total in 1997. Those 55 or older were 21 percent of the total by 1985 and 26 percent in 1997. (See appendix table 6-24.)

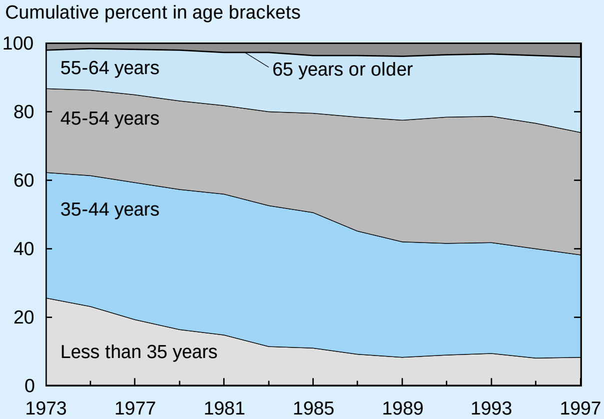
Starting in 1994, provisions of the Age Discrimination in Employment Act became fully applicable to universities and colleges; academic institutions could no longer require faculty to retire at a set age.[38] This development led to concerns about the potential ramifications of an aging professorate for universities' organizational vitality, institutional flexibility, and

[36]Pre-1985 estimates are unreliable because of the low number of computer science degree-holders in the sample.

[37]These trends may have been influenced by the relative field balances in academic R&D funds. See "Expenditures by Field and Funding Source" earlier in this chapter.

[38]A 1986 amendment to the Age Discrimination in Employment Act of 1967 prohibited mandatory retirement on the basis of age for almost all workers. Higher education institutions were granted an exemption through 1993, allowing termination of employees with unlimited tenure who had reached age 70.

Figure 6-16.
Age distribution of full-time doctoral science and engineering faculty: 1973–97



NOTE: Faculty includes full, associate, and assistant professors plus instructors.

See appendix table 6-24. *Science & Engineering Indicators – 2000*

financial health. These concerns were the focus of study by the National Research Council (NRC). The study concluded that "overall, only a small number of the nation's tenured faculty will continue working in their current positions past age 70" (NRC 1991, 29), but added: "At some research universities a high proportion of faculty would choose to remain employed past age 70 if allowed to do so" (NRC 1991, 38).

Data available now suggest that, for the system as a whole over the past decade, there has been little substantial change in terms of retirement behavior. Across all of higher education, about 3–4 percent of full-time faculty stays on beyond age 64, without any major changes over the past decade. As anticipated by the NRC study, on average, faculty at research universities tend to keep working somewhat longer than those elsewhere, but this has been the case for the entire 1973–97 period. The 1995–97 estimate of 4–5 percent for those older than 64 is in the estimated range for the entire past decade.[39] (See appendix table 6-25.)

It is also worth noting that research universities have managed to work toward a relatively more balanced age structure among their full-time faculty than is seen in other types of universities and colleges. (See figure 6-17.) The faculty age distribution in research universities tended to be older, on average, than that of other academic institutions through the early 1980s, but that tendency has since reversed. By 1997, research universities had a greater share of their full-time faculty in the under-45 age brackets than other institutions, and a slightly greater share in the above-59 brackets as well. (See appendix table 6-25.)

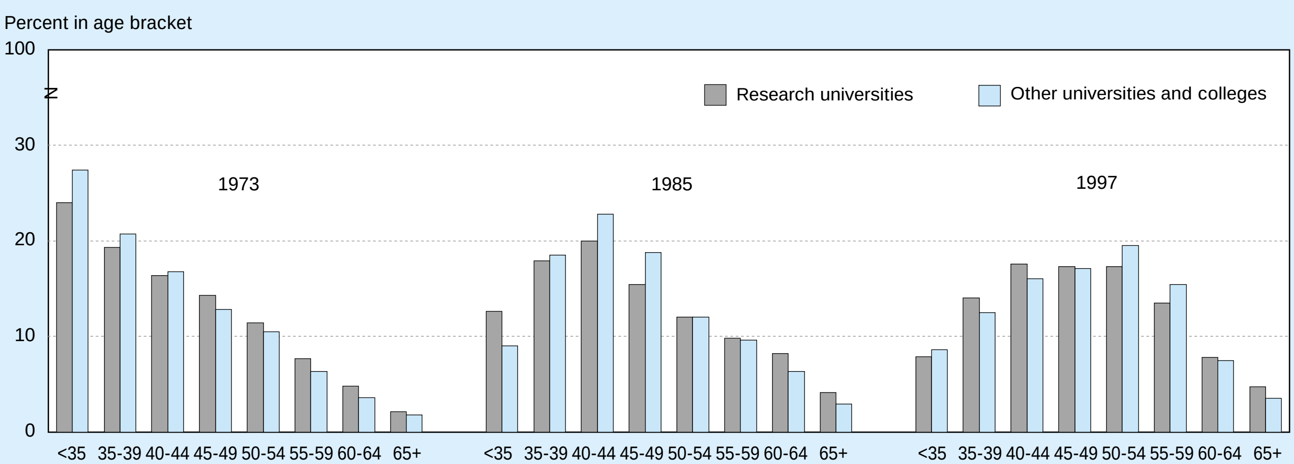
New Ph.D.s Enter Academia, but the Nature of Their Appointments Has Changed[40]

The hiring by universities and colleges of people with newly earned S&E doctorates provides a leading indicator of the composition of the future academic teaching and research workforce. However, the small number of new entrants rela-

[39]See also "Age and Retirement" in chapter 3.

[40]No trend data exist on detailed in- and outflows. The data reported here are "snapshots" of the number and demographic characteristics of doctorate-holders in academic employment who had earned their degree in the three years preceding the survey.

Figure 6-17.
Age distribution of full-time doctoral science and engineering faculty in research universities and other institutions: 1973, 1985, and 1997



NOTES: Faculty includes full, associate, and assistant professors and instructors. Research universities are defined by the Carnegie Corporation for the Advancement of Teaching by their program scope, Ph.D. production, and Federal funding volume.

See appendix table 6-25. *Science & Engineering Indicators – 2000*

tive to the size of the existing academic employment pool ensures that coming changes will unfold gradually.

The number of recent S&E Ph.D.s—defined as those who had earned their doctorate in the three years preceding the survey year—who were hired into academic positions declined gradually from 25,000 in 1973 through the early 1980s, when it reached a low of 20,500. Starting in 1987, it rose again and reached 29,000 in 1997. These new entrants into academia represented approximately half of all recent S&E doctorate-holders entering U.S. employment. (See appendix table 6-26.)

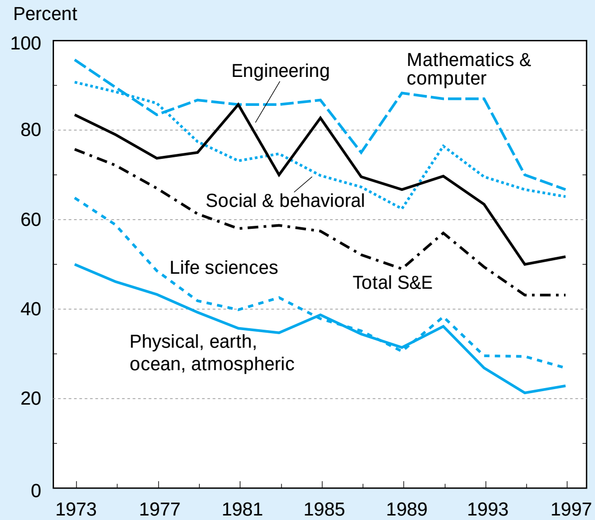
But the nature of academic employment for these young Ph.D.s has shifted considerably over this period. In 1997, only 41 percent reported full-time faculty appointments, compared with 76 percent in the early 1970s. Concurrently, the proportion holding postdoctorate positions increased steeply, rising from 13 percent to 41 percent;[41] other types of appointments have risen from 10 to 18 percent. (See appendix tables 6-26 and 6-27.)

The decline in the proportion of new S&E doctorate-holders with full-time faculty positions affected all fields. To some extent, these trends reflect the growing importance of early-career postdoctoral appointments in a number of fields; but the declines were also evident in those degree fields with relatively small numbers of postdoctorates. (See figure 6-18.) In the combined physical and environmental sciences, roughly one in five received a faculty appointment; in the life sciences, one in four. This compared with half or more than half of those with doctorates in engineering, mathematics and computer sciences, and social and behavioral sciences. (See appendix table 6-27.)

These changes have also affected the ability of recent S&E Ph.D.s hired into academia to enter the tenure track. While about three-quarters of all those hired into a *faculty* position were on the tenure track, few recent S&E doctorates received such an appointment. Overall, only one out of every three recent S&E doctorates hired into academia received such an offer.

The composition of these recent academic doctorate-holders has shifted noticeably over the more than two decades covered here, reflecting the changes in the population earning doctorates in science and engineering.[42] The proportion of women has risen from 12 to 39 percent. The proportion of underrepresented minorities has grown from 2 to 8 percent, of Asians and Pacific Islanders from 5 to 21 percent, and of non-citizens[43] from 8 to 27 percent. Similar trends are evident among those in full-time faculty positions, with these differences: Underrepresented minorities are somewhat better represented in the faculty segment than in overall employment, while Asian and Pacific Islander and non-citizen doctorate-holders are less well represented, especially since 1993. (See appendix table 6-26.)

Figure 6-18.
Percentage of academically employed recent S&E Ph.D.s with full-time faculty status, by major field group: 1973–97



NOTES: Recent Ph.D.s have earned their doctorate in the three years preceding the survey year. Faculty positions include full, associate, and assistant professor and instructor.

See appendix table 6-27. *Science & Engineering Indicators – 2000*

The field composition of these recent Ph.D.s reflects the larger employment changes. In 1997, 37 percent were in the life sciences (up from 28 percent in 1973), 12 percent were in the physical sciences (after dropping from 16 percent in 1973 to 10 percent in 1983), 6 percent were in mathematics (down from 9 percent in 1973), and 17 percent were in the social sciences (down from 23 percent in 1973). But their field distribution in full-time faculty and postdoctoral positions differs from this total employment picture, reflecting the fields' different propensities to hire new Ph.D.s into the faculty-track, as well as the general rise of postdoctoral appointments. Among postdoctorates, 54 percent were in the life sciences (compared to a life sciences share of 37 percent in total employment); 19 percent were in the physical sciences (versus a physical sciences share of 12 percent in total employment). Conversely, among those with faculty positions, 29 percent were in the social sciences, versus a 17 percent social sciences share of all recent academic S&E Ph.D.s. (See appendix table 6-27.)

[41]An accurate count of postdoctorates is elusive, and the reported increase may be understated. A postdoctoral appointment is defined here as a temporary position awarded primarily for gaining additional training in research. The actual use of the term, however, varies among disciplines and sectors of employment. In academia, some universities appoint postdoctorates to junior faculty positions which carry fringe benefits; in others, the appointment may be as a research associate. Some postdoctorates may not regard themselves as genuinely "employed." Also see "Postdoctoral Appointments" in chapters 3 and 4.

[42]The consequences of these demographic trends in the hiring of recent Ph.D.s for the composition of the broader academic doctoral S&E workforce are discussed in earlier sections of this chapter dealing with women and minorities.

[43]Includes those in permanent and temporary visa status at time of doctorate.

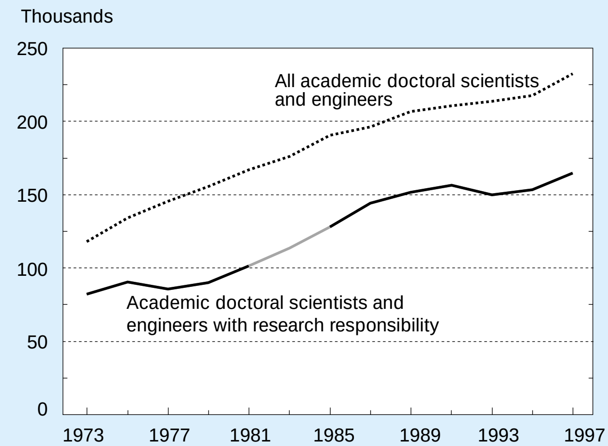
Research and Teaching Activities[44]

In academic settings, teaching, research, and research training are often inextricably intertwined. The conduct of academic research contributes to the production of new knowledge, educated students, and highly trained research personnel. Most academic scientists and engineers pursue teaching, research, and other duties in a mix that may change with the time of year and the course of their careers.

Participation in Academic Research and Development Is Once Again Increasing

U.S. universities and colleges are an indispensable resource in the U.S. R&D system, not only for their education and training functions: they conduct 12 percent of the Nation's total R&D, 27 percent of its basic and applied research, and 48 percent of its total basic research. (For more detail, see chapter 2.) A measure of the degree of faculty and staff participation in academic R&D can be constructed from S&E doctorate-holders' designation of one of four research functions[45] as a primary or secondary work responsibility. This yields a lower-bound estimate of the size of the academic doctoral research workforce broadly defined.[46] By this measure, in 1997 an estimated 164,700 academic doctoral scientists and engineers were engaged in some form of R&D,[47] up from a range of 80,000 to 90,000 during the 1970s. (See figure 6-19.) Between 1995 and 1997, the number of academic researchers, which had been essentially stable since the late 1980s following earlier robust growth, increased by 7 percent—by far its strongest increase in the decade. (See appendix table 6-28.)

Figure 6-19.
Total employed academic doctoral scientists and engineers and those with research responsibility: 1973–97



Note. Research responsibility is defined as reported primary or secondary responsibility for R&D. Numbers for 1981–85 are extrapolated: some respondents were not asked their secondary work responsibility (13, 7, and 13 percent, respectively).

SOURCE: National Science Foundation, Division of Science Resources Studies, Survey of Doctorate Recipients, special tabulation.

See appendix table 6-28. *Science & Engineering Indicators – 2000*

Approximately 71 percent of all academic doctoral scientists and engineers in 1997 were engaged in research or development activities, but this varied by field. At the high end—75 to 79 percent—were engineering, environmental sciences, and life sciences. Mathematics, psychology, and the social sciences reported the lowest levels of research activity, ranging from 59 to 66 percent. These field differences in the levels of research intensity have been fairly consistent over time.

The field composition of academic researchers has remained generally stable, with one exception: The relative employment shift noted earlier away from doctorates in the physical sciences and toward the life sciences is also evident in the research workforce. The share of physical science degree-holders among academic researchers (as defined here) has declined from 20 to 13 percent since 1973; that of the life science Ph.D.s has increased from 32 to 35 percent over the period. Other fields have experienced marginal gains or losses. (See appendix table 6-28.)

A rough indicator of the relative balance between teaching and research may be obtained by an examination of responses of academic doctoral scientists and engineers to a question about their primary work responsibility. The number of those reporting teaching as their primary work responsibility rose from 73,300 in 1973 to 101,000 in 1985 and fluctuated around the 100,000 mark before rising to 105,400 in 1997. In contrast, the number of those identifying research as their primary work responsibility increased without interruption from 27,800 in 1973 to 88,600 in 1997. (See appendix table 6-29.)

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[44]This material is based on individual respondents' reports of their primary and secondary work responsibilities. The data series—which is drawn from SDR—is reasonably consistent for the 1973–89 period: respondents were asked to designate primary and secondary work responsibilities from a list of items, the core majority of which remained unchanged. Since 1991, however, primary and secondary work responsibility has had to be inferred from reports of the activities on which respondents spent the most and the second-most amount of their average weekly work time. These two methods yield close—but not identical—results, so the SDR must be considered to produce a rough indicator only. In addition, some respondents in 1981–85 (13, 7, and 13 percent, respectively) were sent a shortened version of the questionnaire that did not ask about secondary work responsibility. For these respondents and these years, secondary work responsibility was estimated using full-form responses, based on field and type of position held.

[45]The choices, based on NSF's Survey of Doctorate Recipients, and for which definitions are provided, include basic and applied research, development, and the design of equipment, processes, structures, and models.

[46]The estimate fails to account for respondents who ranked research third or lower in their ordering of work responsibilities. Additionally, for 1981 through 1985, some respondents who received short forms of the survey questionnaire could not record a secondary work responsibility, thus resulting in a definite undercount for these years. All estimates are calculated based on individuals who provided valid responses to this item.

[47]An approximate 1993 estimate of the nondoctoral researcher component, excluding graduate research assistants, was derived from the U.S. Department of Education's National Survey of Postsecondary Faculty (NCES 1994). This component was estimated to be approximately 10 percent the size of the doctoral research workforce, and to be concentrated in the life sciences (75 percent) and engineering (10 percent). However, an estimate not restricted to that survey's definition of faculty, derived from SESTAT, NSF's data system on scientists and engineers, puts the number at about 21,000 (NSF 1999j).

In 1997, fewer than half of all respondents—45 percent—selected teaching as their primary work responsibility, a decline from 63 percent in 1973. While some of this decline is driven by the increasing number of postdoctorates on campus, a similar drop—from 69 to 53 percent—is observed for those in full-time faculty ranks. The increasing designation of research activities as primary work responsibility strongly suggests that the relative balance between teaching and research has shifted toward the latter, at least in the perception of these respondents. Those with other types of primary work responsibility—for administrative or managerial functions, service activities, and the like—constituted 13 to 19 percent of the total, and 11 to 17 percent among full-time faculty over the period, and thus have little influence on the apparent shift toward increased research emphasis. (See appendix table 6-30.)

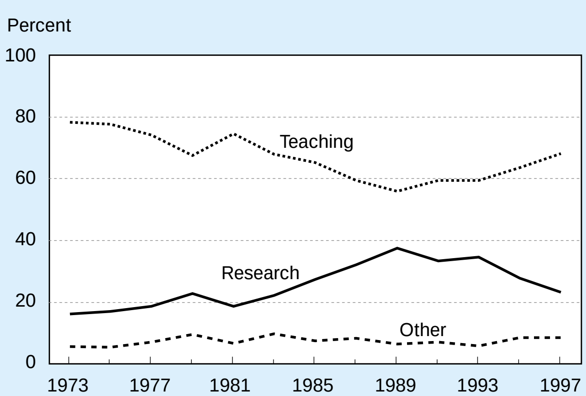
S&E doctorates in full-time faculty positions who earned their Ph.D. in the three years preceding the survey year show an interesting variation of this trend. From 1973 through the late 1980s, their percentage reporting teaching as primary responsibility declined from 78 to 56 percent, while that reporting research as primary rose from 16 to 38 percent. In the 1990s, these trends have reversed, with 68 percent choosing teaching and 23 percent designating research in 1997. (See figure 6-20 and appendix table 6-31.)

Federal Support of Academic Researchers

In 1997, 39 percent of the academic doctoral scientists and engineers reported receiving Federal funding for their research. (See appendix table 6-32.) This was in line with 1993 and 1995 findings, even as the number of academic researchers has expanded. These 1990s numbers reflect reports based on a question about the week of April 15 of the SDR survey year; those from earlier years (except 1985) were based on Federal support received over an entire year. If the volume of academic research activity is not uniform over the entire academic year, but varies to accommodate teaching and other activities, a one-week or one-month reference period will understate the number supported over an entire year.[48] Thus, the 1993–97 numbers (and 1985) cannot be compared directly to results for the earlier years. This earlier—1973–91—series indicates a decline in the proportion of federally supported researchers that coincided with stagnant real Federal R&D funds to academia during much of the 1970s (see chapter 2), followed by a rise in the proportion supported during the 1980s, especially during the latter half when Federal academic R&D funds again rose robustly.

Notable and persistent field differences exist in the proportion of researchers supported by Federal funds.[49] Above the overall S&E average are those with doctorates in the life, environmental, and physical sciences and engineering. Clearly below the mean are those in mathematics, psychology, and the social sciences. The relative position of these fields has not changed substantially over the past two decades. (See appendix table 6-32.)

Figure 6-20.
Distribution of primary work activity of recent S&E Ph.D.s in full-time academic faculty positions: 1973–97



NOTE: Recent Ph.D.s have earned their doctorate in the three years preceding the survey year.

See appendix table 6-31. *Science & Engineering Indicators – 2000*

Science and Public Policy (Steelman report)
Part One—Science for the Nation, I.
Science and the National Interest

Areas for United States Action

In light of the world situation and the position of science in this country, this report will urge:…

5. That a Federal program of assistance to undergraduate and graduate students in the sciences be developed as an integral part of an overall national scholarship and fellowship program. (Steelman 1947, 6.)

Financial Support for S&E Graduate Education

U.S. research universities have traditionally coupled advanced education with research—in the process providing scientific and engineering personnel as well as generating new knowledge. This integration of research and advanced training in S&E has served the country well as U.S. research universities attract graduate students from across the nation and the world. Upon receipt of their advanced degrees, these students set out to work in many sectors of the U.S. and other

[48]Indirect evidence that the extent of support is understated can be gleaned from the number of senior scientists and postdoctorates supported on NSF grants. This number is published annually as part of NSF's budget submission. It bears a relatively stable relationship to numbers derived from SDR in 1987, 1989, and 1991, but diverges sharply starting in 1993. (The figures from the two data sources are never identical, however, since NSF's numbers reflect those funded in a given fiscal year, while SDR numbers reflect those who have support from NSF regardless of when awarded.)

[49]The relative field shares of federally supported researchers appear to be stable across recent survey years, that is, they are relatively unaffected by changes in the survey reference period. The distribution (but not the estimated number) based on NSF estimates is quite similar.

economies, using the skills and knowledge they have acquired to meet a broad range of challenges.

This close coupling of education and research is reflected in the variety of forms in which financial support is provided to S&E graduate students, and particularly to those who are pursuing doctoral degrees. Support mechanisms include fellowships, traineeships, research assistantships (RAs), and teaching assistantships (TAs). Sources of support include Federal agency support, non-Federal support, and self-support. See "Definitions and Terminology" below for fuller descriptions of both mechanisms and sources of support. Most graduate students, especially those who go on to receive a Ph.D. degree, are supported by more than one source and one mechanism during their time in graduate school, and individual graduate students may even receive support from several different sources and mechanisms in any given academic year.

This section focuses on both sources and mechanisms of financial support, with special emphasis on the role of the research assistantship, since this form of support is so closely linked to the availability of academic R&D funds. Financial support is examined both for students who have just received their S&E doctorate degree and for all full-time S&E graduate students, since different types of information are available for these two distinct groups (see footnotes 51 and 52). Many of the discussions about U.S. graduate education focus on the appropriateness of the mechanisms currently used to support graduate students.[50] Documentation of the current structure and how it has evolved over time helps facilitate these discussions. For a more in-depth treatment of graduate education in general, see chapter 4, "Higher Education in Science and Engineering." For discussion of the relationships between financial support and graduate educational outcomes, see "Graduate Modes of Financial Support and Time to Degree" and "Relationship Between Support Modes and Early Employment of Recent S&E Ph.D.s." sidebars later in this chapter.

Definitions and Terminology

- **Fellowships** include any competitive award (often from a national competition) made to a student that requires no work of the recipient.
- **Traineeships** are educational awards given to students selected by the institution.
- **Research assistantships** are support given to students for which assigned duties are primarily devoted to research.
- **Teaching assistantships** are support given to students for which assigned duties are primarily devoted to teaching.
- **Other mechanisms of support** include work/study, business or employer support, and support from foreign governments that is not in the form of one of the earlier mechanisms.
- **Self-support** is support derived from any loans (including Federal loans) or from personal or family contributions.
- **Federal support** is support received from Federal agencies including through the GI bill and members of the Armed Forces whose tuition is paid by the Department of Defense.
- **Non-Federal support** is support received from the student's institution, from state and local government, from foreign sources, from nonprofit institutions, and from private industry.

Support of S&E Graduate Students[51] and S&E Doctorate Recipients[52]

Trends in Support

Full-time S&E graduate student enrollment registered a slight decline in 1997 for the third consecutive year, as did the number of such students whose primary source of support was the Federal Government.[53] The number of those whose primary source of support was from non-Federal sources rose slightly after declines in 1995 and 1996. (See appendix table 6-33.)

The proportion of graduate students with research assistantships (RAs) as their primary support mechanism increased from 22 to 28 percent between 1980 and 1989, a level about where it has since remained. This shift toward the use of RAs

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[50]See COSEPUP (1995), NSB (1996), and NSF (1996a).

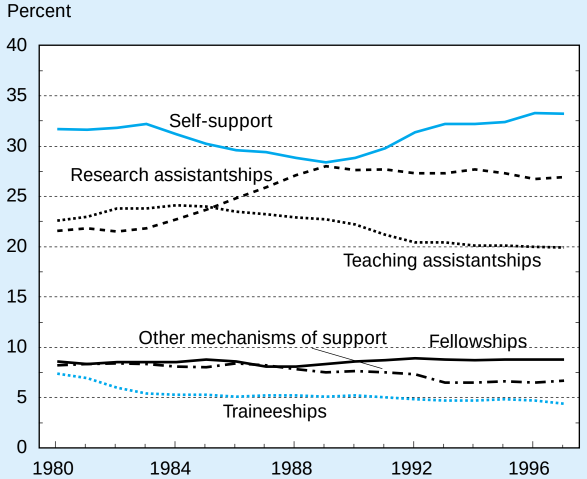
[51]The data presented on mechanisms and sources of support for S&E graduate students are from the NSF-NIH annual fall Survey of Graduate Students and Postdoctorates in Science and Engineering (NSF 1999f). In this survey, departments report the primary (largest) source and mechanism of support for each full-time degree-seeking S&E graduate student. No financial support data are collected for part-time students. Many of the full-time students may be seeking master's degrees rather than Ph.D. degrees, particularly in fields such as engineering and computer sciences. Since departments are aware of both primary sources and mechanisms of support for their students, both of these can be examined. Throughout this section, S&E includes the health fields (medical sciences and other life sciences).

[52]The data presented on mechanisms of support for S&E doctorate recipients are from the annual Survey of Earned Doctorates (NSF 1999i). Students who have just received their Ph.D.s are asked to respond to this survey. They are asked to identify their primary and secondary sources of support during graduate school as well as to check all other sources from which support was received. Validation studies on the quality of the data received from respondents to this survey indicate that the information on mechanisms of support is much better than that on sources. (See NRC 1994.) This is especially true for students whose primary support is a research assistantship, since they may not always know who is providing the funds that are supporting them. For this reason, the discussion of doctorate recipients is confined to mechanisms of support except for self-supported students. Twelve percent of the respondents in 1997 did not report a primary mechanism of support.

[53]Total Federal support of graduate students is underestimated since reporting on Federal sources includes only direct Federal support to a student and support to research assistants financed through the direct costs of Federal research grants. This omits students supported by departments through the indirect costs portion of research grants; such support would appear as institutional (non-Federal) support, since the university has discretion over how to use these funds.

was offset by a decline in the proportions supported by traineeships and self-support. During the 1990s, the proportion of students with traineeships as their primary support mechanism continued to decline, and the proportion of those with teaching assistantships (TAs) also began to decline. The relative decline in the use of these two mechanisms was balanced by an increase in the proportion reporting self-support. (See figure 6-21.)

Figure 6-21.
Primary support mechanisms for full-time S&E graduate students: 1980–97



NOTE: S&E also includes the health fields (medical sciences and other life sciences).

See appendix table 6-33. *Science & Engineering Indicators – 2000*

These overall shifts in the relative importance of primary RA support occurred for both students supported primarily by Federal sources and for those supported by non-Federal sources (this excludes students whose primary source of support is self-support). Among students whose primary source of support was the Federal Government, the rise in the proportion of those with an RA was offset by a fall in the proportion of those with a traineeship. Among students whose primary source was non-Federal, the shift toward RAs was balanced by a shift away from TAs.

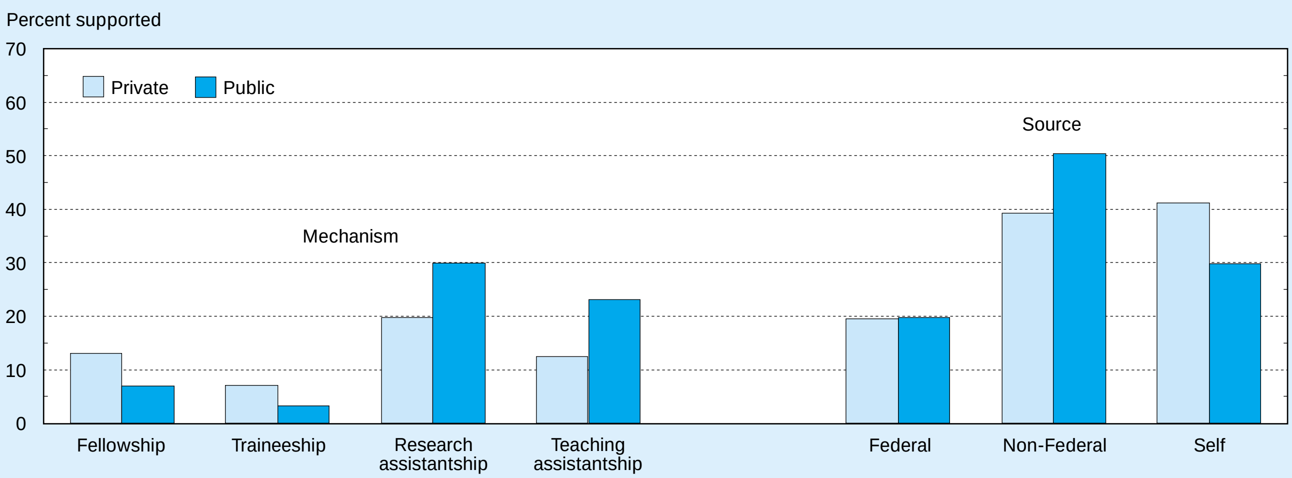
Patterns of Support by Institution Type

The proportion of full-time S&E graduate students with primary support from various sources and mechanisms differs for private and public universities. (See figure 6-22 and appendix table 6-34.) A larger proportion of full-time graduate students rely primarily on self-support in private academic institutions as opposed to those in public institutions—41 versus 30 percent in 1997.

Non-Federal sources are the primary source of support for a larger proportion of students in public institutions (50 percent) than in private ones (39 percent). About 20 percent of students in both private and public institutions receive their primary support from the Federal Government.

A larger proportion of students attending public academic institutions rely on research assistantships and teaching assistantships as their primary support mechanism (30 percent and 23 percent, respectively) than those attending private institutions (20 percent and 12 percent, respectively). This is balanced by greater reliance on fellowships and traineeships in private institutions (13 percent and 7 percent, respectively) than in public ones (7 percent and 3 percent, respectively).

Figure 6-22.
Primary support of full-time S&E graduate students, by mechanism and source for private and public universities: 1997



NOTES: Mechanism percentages do not total to 100 percent because other mechanisms are not included. S&E also includes the health fields (medical sciences and other life sciences).

See appendix table 6-34. *Science & Engineering Indicators – 2000*

Graduate Modes of Financial Support and Time to Degree

There is considerable interest in whether the amount and type of financial support given to graduate students has an effect on outcomes such as degree completion rates, time to degree, and productivity and success in the labor market. Unfortunately, it is extremely difficult to examine many of these impacts analytically either because of the absence of data, the subjective nature of the data that is available, or the inability to capture the outcomes quantitatively. In addition, most graduate students depend on multiple sources and mechanisms of support while in graduate school, and frequently on different sources and mechanisms in different phases of graduate work. This makes it quite difficult, if not impossible, to identify a one-to-one relationship between a student and a support source or mechanism.

Despite these difficulties, various studies have looked at some aspects of graduate support and student outcomes. A recent review of this literature summarized the results as follows (Bentley and Berger 1998a):

- ♦ The bulk of the evidence suggests that students receiving financial support enjoy higher completion rates and shorter time to degree than students without financial support.
- ♦ The evidence of the differential effects of alternative support mechanisms on completion rates is inconsistent. However, students holding fellowships appear to finish doctoral programs more quickly than teaching and research assistants.

A recent analysis prepared for NSF (Bentley and Berger 1998b) examined the effects of primary graduate support mechanisms reported by science and engineering research doctorate recipients on time to degree. Early on in this analysis it was found that the primary graduate support mechanisms identified by these doctorate recipients are not randomly distributed across factors that are likely to affect outcomes. Students majoring in some fields are more likely to receive one type of support than those majoring in others. Nonrandom assignment of primary support mechanisms across personal characteristics was also observed. For example, older students who are married and have dependents are more likely than other groups to report being self-supported. Men are more likely than women to report primary support from research assistantships. Students who do not switch fields between degrees are more likely to rely on research assistantships for primary support, while field switchers are more likely to be self-supporting. Because of this nonrandom assignment, it was necessary to use multivariate analyses to measure the impacts of support mechanisms on outcomes. Variables included in this analysis in addition to primary support mechanism include doctoral field, personal characteristics (for example, age, race/ethnicity, citizenship, marital status), parents' education, field and institution paths (that is, how often individuals switch academic fields and institutions), and cumulative debt.

The study found relatively large differences in the simple averages of time to degree* computed across alternative support mechanisms before the variables mentioned above were included in the analysis. For example, the mean total time to degree for students primarily supported by fellowships was 7.86 years, significantly less than the 10.33 years for self-supporting students. However, much of the differences in average time to degree across support mechanisms disappear when the effects of the additional variables are accounted for in the multivariate analysis. In the example above, after controlling for those other factors affecting time to degree, students primarily supported by fellowships complete their Ph.D. just 0.65 years faster than self-supporting students, rather than 2.47 years faster. The multivariate analysis also showed relatively small differences in time to degree across alternative types of support. For example, students supported by fellowships complete doctorates only about one-third of a year faster than students supported by teaching assistantships, and the latter complete degree requirements nearly as fast as research assistants.

Even after controlling for a number of variables, the study had several limitations that need to be considered in interpreting the findings. One of the main difficulties is a selection problem that is not easily overcome. Fellowships and assistantships are probably awarded on the basis of ability and achievement. Some of the measured effects of these types of support may be due to student characteristics, rather than to the receipt of the award. For example, if students awarded fellowships have better academic credentials than others do, one might expect them to finish their doctorates more quickly. To the extent that graduate support allocation decisions are successful in sorting students by merit and aptitude, it becomes more difficult to statistically isolate the effect of receiving graduate support from the effects of other student differences.

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*The discussion below refers to total time to degree, which is defined as years elapsed between the date of the bachelor's degree and the date of the doctorate. There are alternative measures of time to degree that can be analyzed including graduate time to degree (years elapsed between the date of entry into the first graduate program and the date of the doctorate) and registered time to degree (number of years registered in the graduate program before receiving the doctorate).

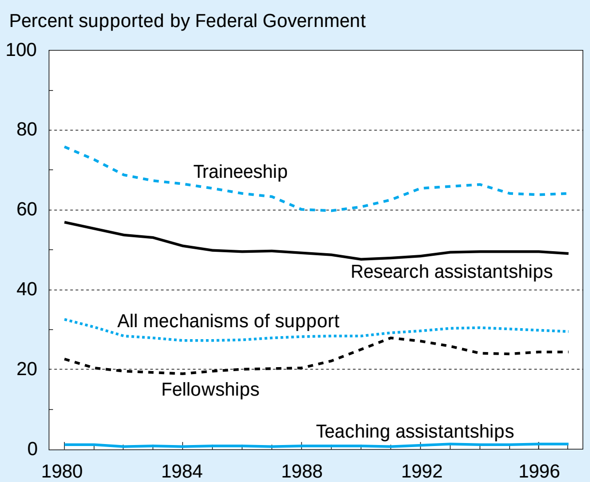
The Federal Government plays a larger role as the primary source of support for some mechanisms than for others. (See figure 6-23.) A majority of traineeships in both private and public institutions (54 percent and 73 percent, respectively) are financed primarily by the Federal Government, as are 60 percent of the research assistantships in private institutions and 46 percent in public institutions. The Federal Government provides the primary support for less than 30 percent of fellowships and less than 2 percent of teaching assistantships in both public and private institutions.

Support Patterns for All S&E Graduate Students Versus Doctorate Recipients

Most full-time S&E graduate students do not go on to receive a Ph.D., and many never intend to do so. Consequently, it is likely that the financial support patterns of full-time S&E graduate students will differ from those of S&E Ph.D. recipients. While the data from the two surveys are not strictly comparable, it is useful to compare the primary support patterns of those students who do earn a Ph.D. with the patterns for all full-time S&E graduate students to see if they provide a rough indicator of differences among these two groups.[54] Thirty-four percent of the students receiving their science and engineering Ph.D.s in 1997 reported that their primary mechanism of support during their time in graduate school was a research assistantship. This is somewhat higher than the percentage (27 percent) of full-time science and engineering students for whom a research assistantship was reported as the primary mechanism of support. Fellowships and teaching assistantships were reported less frequently as a primary mechanism of support by those students who earned an S&E Ph.D. (2 percent and 15 percent, respectively) than for all full-time S&E graduate students (9 percent and 20 percent, respectively). Traineeships, however, were reported more frequently by those receiving an S&E Ph.D. (7 percent) than for graduate students in general (4 percent). A considerably smaller percentage of students receiving an S&E Ph.D. reported self-support as their primary means of support (20 percent) than did graduate students in general (33 percent). (See appendix tables 6-35 and 6-36.) For a brief discussion of overall rather than primary support for S&E Ph.D.s see sidebar, “Multiple Modes of Financial Support for S&E Ph.D.s.”

[54]As noted earlier, the data for these two groups are derived from two distinct surveys with different reporting entities and different time frames.

Figure 6-23.
Percentage of full-time S&E graduate students with the Federal Government as primary source of support, by primary mechanism of support: 1980–97



NOTES: Data shown here do not include students for whom self-support is their primary source of support. S&E also includes the health fields (medical sciences and other life sciences).

See appendix table 6-33. *Science & Engineering Indicators – 2000*

Support Patterns for S&E Doctorate Recipients by Citizenship, Sex, and Race/Ethnicity

The data on financial support for S&E Ph.D.s also permit one to look at differences in support patterns by citizenship status, sex, and race/ethnicity;[55] this is not possible with the graduate student data.[56] (See appendix table 6-37.) Foreign S&E Ph.D. recipients—whether on temporary or permanent visas—were more likely than U.S. citizens to report a research assistantship (44 and 45 percent versus 32 percent) or a teaching assistantship (20 and 19 percent versus 14 percent) as their primary support mechanism and less likely than U.S. citizens to report a fellowship (1 percent versus 3 percent), traineeship (5 and 8 percent versus 9 percent), or self-support (11 and 15 percent versus 27 percent).[57]

Among U.S.-citizen doctorate recipients, men were much more likely than women to report a research assistantship (35 versus 27 percent) and much less likely to report self-support (22 versus 33 percent) as their primary support modes. Although sex differences also existed in the use of fellowships, traineeships, and teaching assistantships, these were much smaller than the above-mentioned differences.

Also, among U.S.-citizen S&E Ph.D.s, underrepresented minorities (American Indians, Alaskan Natives, blacks, and Hispanics) were less likely than either Asians and Pacific Islanders or whites to report research assistantships (21 percent versus 41 and 32 percent) and teaching assistantships (8 percent versus 10 and 15 percent) as their primary support mechanism and more likely to report fellowships (6 percent versus 4 and 3 percent) and traineeships (16 percent versus 9 and 8 percent). They were also more likely to report self-support (26 percent) than Asians and Pacific Islanders (17 percent), but less likely than whites (28 percent). (See figure 6-24.) See “The Debt Burden of New Science and Engineer-

[55]Since the Survey of Earned Doctorates obtains data from individual respondents, information is available about demographic characteristics such as citizenship, race/ethnicity, and sex.

[56]For information on the distribution of and trends in S&E Ph.D.s by sex, race/ethnicity, and citizenship status, see chapter 4, “Higher Education in Science and Engineering.”

[57]Foreign S&E Ph.D. recipients, especially those on temporary visas, are often not eligible for either Federal loan programs (included in self-support) or Federal fellowships.

Multiple Modes of Financial Support for S&E Ph.D.s

A recent NSF study (NSF 2000a) examined the entire matrix of support patterns of science and engineering (S&E) research doctorates in 1995 (not only their primary forms of support), showing the distribution of various modes of support to individuals. The Survey of Earned Doctorates, which served as the main source of data for this study, allowed new Ph.D.s to select from 32 separate support options all the forms of support that they may have used during graduate school. In the study, these 32 support options were combined into 7 modes of support:

- fellowship,
- traineeship,
- research assistantship (RA),
- teaching assistantship (TA),
- own funds,
- loans, and
- other.

The study found that 1995 S&E Ph.D.s commonly relied on more than one mode of support. The average number of modes of support was 2.5 and varied by field, sex, race/ethnicity, and citizenship. Women tended to rely on more support modes than men in S&E as a whole and in most fields. Asians and Pacific Islanders and noncitizens reported fewer modes of support on average than did other groups.

Among S&E Ph.D.s as a whole (looking at all forms of support reported rather than only the primary mode of support), women were more likely to report having used traineeships, their own funds, or loans than were men. Men were more likely than women to receive support in the form of RAs. For the most part, differences between women's and men's reliance on own funds and RAs are related to differences in field of doctorate. Women are more likely than men to be in psychology and in health sciences—fields in which reliance on one's own funds is common—and men are more likely than women to be in engineering and physical sciences—fields in which reliance on RAs is common.

Among both Asian and Pacific Islander and noncitizen S&E Ph.D. recipients, RAs were the most frequently reported modes. In contrast, the support mode identified by the largest percentage of both underrepresented minorities (American Indians, Alaskan Natives, blacks, and Hispanics) and whites was their own funds. Whites and underrepresented minorities were also more likely to report the use of loans than were Asians and Pacific Islanders or noncitizens, and underrepresented minorities were more likely to report the use of both fellowships and traineeships than other groups. Although some of these variations in modes of support were found to be due to field differences, field differences did not explain all of the racial/ethnic variations. For instance, Asians and Pacific Islanders reported the largest use of RAs in every field except the computer sciences and psychology. Also, in every field, a larger percentage of both underrepresented minorities and whites reported using their own funds and loans than did Asians and Pacific Islanders or noncitizens. Further, in almost every field, higher percentages of underrepresented minorities than other groups reported using fellowships and traineeships.

Five combinations of support modes out of a possible 127 were reported by slightly less than half of all 1995 S&E Ph.D. recipients. Two combinations—RA+TA and RA+own funds—accounted for about 20 percent of all combinations of modes. RA+TA+own funds and RA alone were the third and fourth most frequent combinations. TA+own funds was the fifth most frequently used combination. Combinations of support modes differ by sex within some fields. For example, in the health sciences, 12 percent of women and 6 percent of men reported using their own funds as their only mode of support. In mathematics, women and men have the same top four combinations of support but the predominant combination for men was RA+TA and for women TA+own funds.

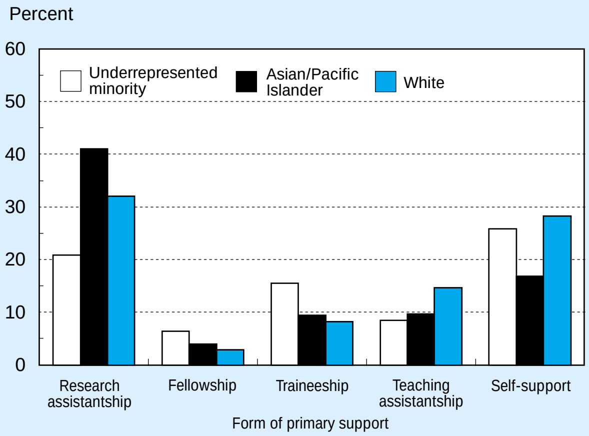
Underrepresented minorities were found to use a wider range of funding combinations and relied more on loans and own funds than did Asians and Pacific Islanders and noncitizens. Each of the five top combinations of modes of support of underrepresented minorities involved use of their own funds and accounted for only 22 percent of minority Ph.D. recipients. In contrast, just under 40 percent of those of Asian or Pacific Islander background received their support from the RA+TA combination or RA alone, and the top five combinations accounted for the support of about 60 percent of those Ph.D.s.

ing Ph.D.s" later in this chapter for differences in the debt situation of U.S. citizen and foreign Ph.D. recipients, among racial/ethnic groups, and between men and women.

Since the field distribution of S&E Ph.D. degrees varies across demographic groups, and the patterns of support differ by S&E field, some of the differences reported above could be mainly the result of degree field distribution differences. However, the data indicate that although degree field distribution does explain a great deal of the difference in relative importance of primary support mechanisms between men and women, it does not account for the differences across either citizenship status or race/ethnicity. (See appendix tables 6-38, 6-39, and 6-40.)

In the case of foreign S&E Ph.D. recipients, the relative importance of RAs and TAs as primary support mechanisms

Figure 6-24.
Primary forms of support for 1997 U.S. citizen S&E Ph.D. recipients, by race/ethnicity



NOTES: Percentages do not total to 100 due to omission of other nonspecified forms of support, nonrespondents, and rounding. Underrepresented minorities include American Indians, Alaskan Natives, blacks, and Hispanics. S&E also includes the health fields (medical and other life sciences).

See appendix table 6-37. *Science & Engineering Indicators – 2000*

found in the aggregate compared to U.S. citizens also holds for most S&E fields, and is particularly strong in both engineering and the computer sciences. Similarly, the lesser relative reliance on self-support holds in all the broad disciplinary areas, while the comparatively minor roles of fellowships and traineeships for foreign doctorate recipients holds in about half of these fields. (See appendix table 6-38.)

Although among U.S. citizens female S&E doctorate recipients were less likely than males to report an RA as their primary support mechanism at the aggregate level, this was not the case in many S&E fields. In five broad fields—mathematics, environmental sciences, biological sciences, psychology, and social sciences—women were either more or equally likely as men to report an RA as their primary support mechanism. (See appendix table 6-39.) In addition, in many fields, differences between men and women in the percentage reporting an RA as their primary support mechanism were in the 1 to 3 percentage point range rather than the 8 percentage point aggregate differential. Only in the computer sciences was this differential large—20 percent of the women reported an RA, compared to 34 percent of the men.

The level of the aggregate difference in reliance on RAs between men and women can be explained by the fact that a much larger percentage of women (29 percent) received their Ph.D. degrees in psychology—a field where RAs are not a very important primary means of financial support—than did men (9 percent). The level of the aggregate difference between sexes in the reliance on self-support as a primary mode of support can be similarly explained. Once again, in this case, individual fields do not follow the aggregate pattern. In the environmental sciences, agricultural sciences, biological sciences, and engineering, women were less likely than men to identify self-support as their primary means of support. And in the fields where women were more likely to rely on self-support than men, only in the health sciences was the difference between them (52 percent versus 39 percent) as large as the aggregate difference reported. In the other fields, differences ranged between 1 and 5 percentage points.

In the case of U.S.-citizen underrepresented minority S&E Ph.D. recipients, the aggregate findings also hold for most broad disciplinary areas. (See appendix table 6-40.) For example, only in the health sciences is the percentage of underrepresented minorities higher than the percentage of white Ph.D. recipients reporting RAs as their primary mechanism of support. And only in the social sciences is the percentage of underrepresented minorities higher than the percentage of Asian and Pacific Islander Ph.D. recipients reporting RAs as their primary mechanism of support.

Science and Public Policy (Steelman report)
Part One—Science for the Nation, IV.
A National Science Program

Scientists for the Future

Our scientific strength depends neither solely upon our present supply of scientists, nor upon those students now being trained. It depends ultimately upon a steady flow of able students into our colleges and universities. What we require as a Nation is to extend educational opportunities to all able young people, leaving it to them to determine the field of study they desire to pursue. In normal times, freedom of choice must be allowed to operate in education, as well as elsewhere, if we are to preserve our free institutions. No agency of the Government is sufficiently far-seeing—nor ever likely to be—to foretell 15 or 20 years in advance the fields in which we shall need most trained people. In free competition, the physical and biological sciences will get their share.

The expanding grants in support of basic research will provide an opportunity for the employment of more graduate students in such research programs. This will enable the universities themselves to choose the best of their present students as research assistants and will in turn result in better scientific training. (Steelman 1947, 35-6.)

Research Assistantships as a Primary Mechanism of Support

Graduate Research Assistantships by S&E Field

Research assistantships accounted for 27 percent of all support mechanisms for full-time S&E graduate students in 1997. However, the mix of support mechanisms, and thus the

Relationship Between Support Modes and Early Employment of Recent S&E Ph.D.s

A recent NSF Issue Brief (NSF 1998a) examined the relationships between the primary mechanism of financial support reported by recent science and engineering (S&E) Ph.D.s* and the sector in which they were employed and their primary work activity within one to two years after conferral of their doctorate.

Since 1979, in every year of the biennial Survey of Doctorate Recipients (odd years), about half of recent S&E Ph.D.s with primary research assistantship, fellowship, traineeship, or teaching assistantship support were working in academic institutions. However, with a few minor exceptions, since 1979 those with primary RA support had a relatively greater propensity for industry employment—and a lower propensity for academic jobs—than those with primary fellowships, traineeships, and teaching assistantships. (See text table 6-5.) For example, in 1995 industry employed a third of those with RA support, but only 21 percent of those with TA support, 19 percent of those with fellowships, and 15 percent of those with traineeships. Academic institutions employed 51 percent of those with RA support, but 61 percent of those with fellowship, 65 percent of those with traineeship, and 66 percent of those with TA support.

A small number of universities—about 125**—dominate the conduct of academic research, while a much larger number—about 1,600—award four-year and advanced degrees in science and engineering. The study found that RA- and fellowship-supported S&E Ph.D.s who did enter academic employment disproportionately ended up working at these research universities. From 1979 to 1995, these institutions employed from 59 to 68 percent of all the recent S&E Ph.D.s who were working in colleges and universities, but 71 to 84 percent of those in academic employment who had primary RA support, and 72 to 90 percent of those with primary fellowship support.

The study also found that although recent S&E Ph.D.s tended to designate research as their primary activity more frequently than teaching, their responses differed with primary support mode. (See text table 6-5.) In 1995, 73 to 75 percent of recent S&E Ph.D.s with research assistantships and fellowships identified research as their primary job activity, compared to 56 percent overall, 54 percent of those with traineeships, and 40 percent of those with a teaching assistantship. This pattern also has been quite consistent since 1979, although 1995 is anomalous for the relationship between traineeships and work activity that appeared to hold during 1979–93.

A significantly greater percentage of those with teaching assistantships as primary support and a significantly smaller percentage of those with a research assistantship were likely to report teaching as their primary work activity than the overall population of recent S&E Ph.D.s. This was true throughout the 1979–95 period. For S&E Ph.D.s with fellowships or traineeships, the propensity to report teaching as their primary work activity varied over these years.

The available data do not provide any information about the causes of these patterns. Therefore it is not clear whether students who desire careers as researchers or in industry seek out RA support or whether the experiences associated with RA support influence the choice of employment sector and type of work sought by recent S&E Ph.D.s. In addition, the relationships between primary support mechanism, employment sector, and primary work activity may in part reflect factors not examined here, particularly distribution of support mechanisms across specific fields and sectoral employment differences across these fields.

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*Data for this analysis were from NSF's annual Survey of Earned Doctorates (primary support mode) and its biennial Survey of Doctorate Recipients (sector of employment and primary work activity). For this analysis, recent S&E Ph.D.s are defined as those receiving their doctorate degree in the two years preceding the biennial Survey of Doctorate Recipients.

**The Carnegie Commission calls them the Research Universities.

role of research assistantships as the primary support mechanism, differs by S&E field. (See appendix table 6-36.) RAs comprise more than 50 percent of the primary support mechanisms for graduate students in atmospheric sciences, oceanography, agricultural sciences, chemical engineering, and materials engineering. They account for less than 20 percent in all the social sciences, mathematics, and psychology.

The number of graduate students with a research assistantship as their primary mechanism of support increased from just over 50,000 in 1980 to a peak of 92,000 in 1994, and by 1997 fell to 88,000. (See appendix table 6-41.) In just about every S&E field, the percentage of graduate students with a research assistantship as their primary means of support was higher in 1997 than in 1980. The largest increases were in the biological sciences (14 percentage points), in both the agricultural and the medical sciences (10 percentage points each), and in a number of engineering fields—electrical/electronic engineering (11 percentage points), chemical engineering (10 percentage points), and civil and industrial engineering (9 percentage points each). (See figure 6-25.)

All S&E Graduate Students Versus Doctorate Recipients

Although not strictly comparable, data from the Ph.D. and graduate student surveys suggest that the relative utilization of a research assistantship as a primary mechanism of sup-

Text table 6-5.
Percent of recent S&E Ph.D.s working in academe or industry, or with research or teaching as primary work activity, by selected primary mechanism of support: 1979–1995

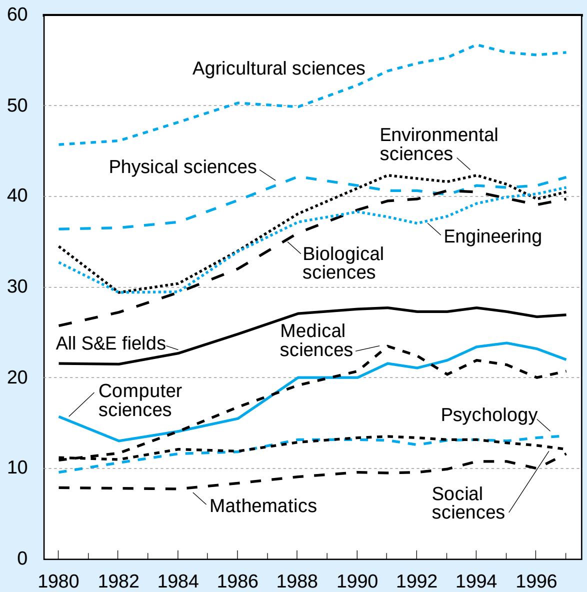
	All	Research assistantship	Teaching assistantship	Traineeship	Fellowship
Work sector					
Academe					
1979	52	49	60	68	56
1981	50	44	61	62	55
1983	49	48	58	60	59
1985	50	49	59	55	65
1987	47	45	60	55	43
1989	49	45	57	68	75
1991	49	46	58	62	63
1993	51	49	71	58	62
1995	54	51	66	65	61
Industry					
1979	21	30	24	14	20
1981	27	39	23	13	27
1983	26	35	26	16	17
1985	25	32	22	17	23
1987	24	31	18	19	26
1989	25	30	23	13	17
1991	26	32	23	20	19
1993	28	34	16	21	28
1995	27	33	21	15	19
Primary work activity					
Research					
1979	47	60	47	52	56
1981	51	76	44	54	73
1983	53	70	50	63	73
1985	53	73	50	71	60
1987	56	76	55	74	66
1989	59	78	59	73	79
1991	56	75	46	64	75
1993	58	75	47	69	80
1995	56	75	40	54	73
Teaching					
1979	24	15	34	24	24
1981	22	11	35	21	17
1983	21	15	28	17	9
1985	20	15	31	12	26
1987	19	12	30	7	21
1989	18	8	31	11	17
1991	19	11	34	17	13
1993	17	8	38	14	11
1995	18	9	35	20	15
Average N	28,487	7,958	4,290	2,833	746

NOTES: Recent S&E Ph.D.s are those receiving their degrees in the two years preceding the survey year of the biennial Survey of Doctorate Recipients. Percentages represent the percent of recent S&E Ph.D.s in each year that work in academe and industry or that report research and teaching as primary work activity, but do not sum to 100 percent since employment sectors other than academe and industry and work activities other than research and teaching are not shown. Industry includes self employment. “Average N” is average number of recent S&E Ph.D.s across the nine survey years for each primary support mechanism and for the “All” category includes all recent S&E Ph.D.s including those with mechanisms not shown (own/family resources, loans, other nonspecified, and missing).

SOURCES: National Science Foundation, Division of Science Resources Studies (NSF/SRS), Survey of Earned Doctorates and Survey of Doctorate Recipients, various years, special tabulations.

Science & Engineering Indicators – 2000

Figure 6-25.
Percentage of full-time S&E graduate students with a research assistantship as primary mechanism of support, by field: 1980–97



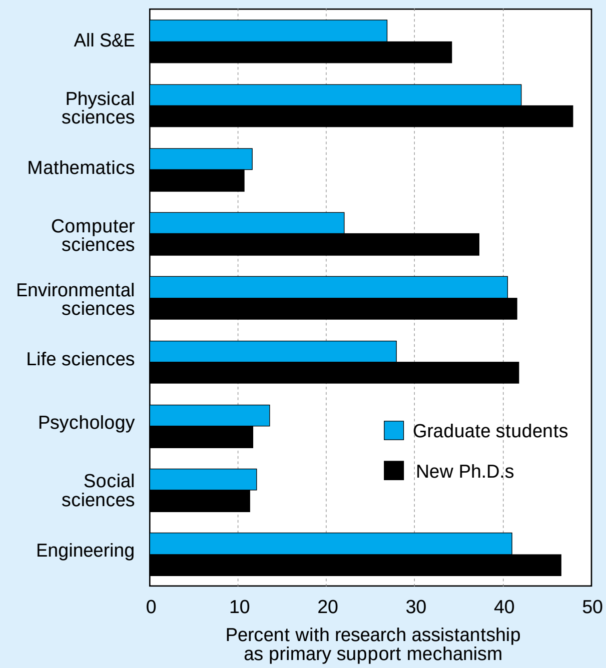
See appendix table 6-41. *Science & Engineering Indicators – 2000*

port was rather similar at a broad disciplinary level between full-time S&E graduate students and S&E Ph.D. recipients. (See figure 6-26.) Research assistantships were once again quite prominent in the physical sciences, environmental sciences, and engineering and much less prominent in mathematics, social sciences, and psychology. However, in both the life sciences and the computer sciences, research assistantships played a much larger role as a primary support mechanism for those receiving their doctorate than for the average full-time S&E graduate student.

Sources of Support

In 1997, about one-third of graduate research assistants were in the life sciences, with an additional 30 percent in engineering and 13 percent in the physical sciences. The Federal Government was the primary source of support for about half of all graduate students with a research assistantship as their primary mechanism of support. (See appendix table 6-42.) This proportion declined from 57 percent in 1980 to about 50 percent in 1985, where it has since remained. (See figure 6-27 and appendix table 6-43.) The Federal role, however, differs by S&E field. The Federal Government was the primary source of support for considerably more than half of the research assistants in the physical sciences (72 percent), the environmental sciences (61 percent), and the computer sciences (60 percent), and for considerably less than half in the social sciences (21 percent) and psychology (31 percent).

Figure 6-26.
Indicator of relative importance of research assistantships as primary mechanism of support for full-time S&E graduate students and S&E Ph.D. recipients, by field: 1997



NOTES: Since the data for graduate students and Ph.D.s are derived from two distinct surveys with different reporting entities and different time frames, these percentages are not strictly comparable. They are only intended to serve as a rough indicator of the similarities and differences between relative use of RAs as a primary support mechanism by the two groups. Life sciences also includes the health fields (medical sciences and other life sciences).

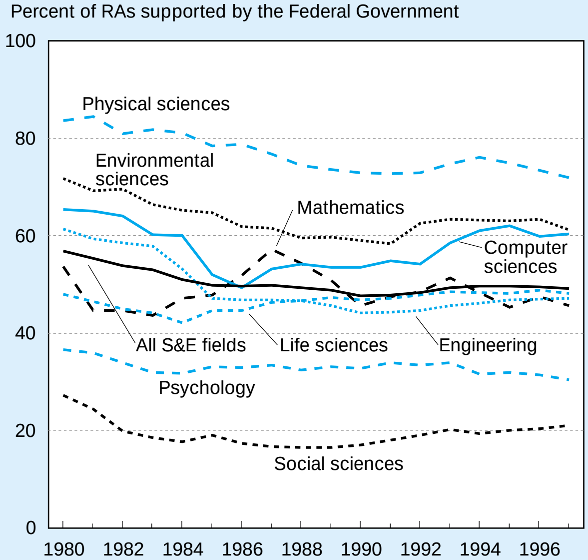
See appendix tables 6-35 and 6-36.
Science & Engineering Indicators – 2000

Federal Agency Support[58]

During most of the 1980s NSF was the Federal agency that was the primary source for the largest number of graduate research assistantships. It was surpassed by the entire HHS in 1989 and by NIH in 1993. (See appendix table 6-44.) Between 1980 and 1997, the percentage of Federal graduate research assistantships financed primarily by NIH increased from about 19 percent to 26 percent, while the percentage financed primarily by NSF increased from 26 percent to a peak of 28 percent in 1984, then fell to 24 percent. The DOD share has fluctuated between 10 and 16 percent over the same period and the USDA share between 6 and 7 percent (since it was first reported in 1985). NASA's share in 1997 (only the second year it was reported) was just under 5 percent.

[58]Only five Federal agencies are reported on individually as primary sources of support to S&E graduate students in the Survey of Graduate Students and Postdoctorates in Science and Engineering: DOD, NSF, USDA, NASA, and HHS, with the latter being reported as two distinct units—NIH and other HHS. DOE has been added to the 1999 survey.

Figure 6-27.
Percentage of full-time S&E graduate students with a research assistantship as primary support mechanism whose primary source of support is the Federal Government, by field: 1980–97



NOTE: Research assistants (RAs) are students for whom a research assistantship is reported as their primary mechanism of support. Life sciences also includes the health fields (medical sciences and other life sciences).

See appendix table 6-43. *Science & Engineering Indicators – 2000*

Just as Federal agencies emphasize different S&E fields in their funding of academic research, it is not surprising to find that they also emphasize different fields in their support of graduate research assistants. HHS and especially NIH concentrate their support in the life sciences (70 percent and 73 percent, respectively), as does USDA (74 percent). DOD concentrates its support in engineering (58 percent). NSF, on the other hand, has a more diversified support pattern, with just over one-third in engineering, 29 percent in the physical sciences, and 10 percent each in the environmental and the life sciences. (See figure 6-28 and appendix table 6-45.) Although an agency may place a large share of its support for research assistants in one field, it may not necessarily be a leading contributor to that field. (See figure 6-29 and appendix table 6-46.) NSF is the lead supporting agency in mathematics (41 percent of federally supported RAs), the environmental sciences (41 percent), the physical sciences (37 percent), and in engineering (29 percent). NIH is the lead support agency in the life sciences (60 percent), psychology (56 percent), and sociology (36 percent). DOD is the lead support agency in the computer sciences (43 percent) and in electrical engineering (45 percent), and also provides an almost identical level of support as NSF for total engineering. USDA is the lead support agency in the agricultural sciences (56 percent) and economics (52 percent). NASA is the lead support agency in astronomy (45 percent) and aeronautical/astronautical engineering (36 percent).

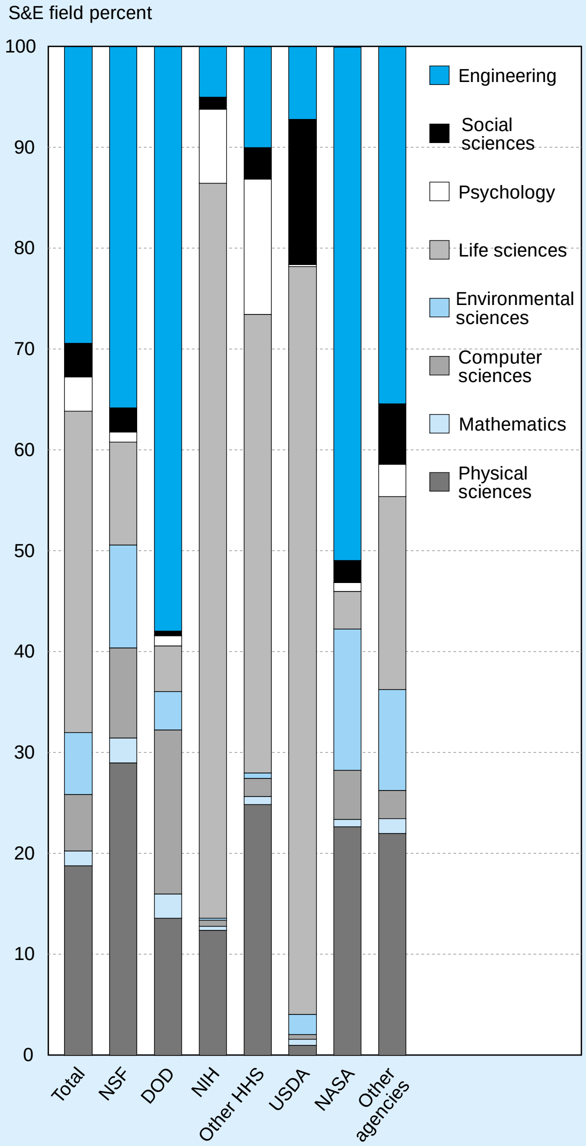
The Spreading Institutional Base

During the 1980–97 period, the number of universities and colleges reporting at least one full-time S&E graduate student with a research assistantship as his or her primary mechanism of support has fluctuated between 400 and 435, with a slight upward trend, reaching its highest level in 1993. Not surprisingly, however, there was basically no change in the number of currently designated Carnegie research or doctorate-granting institutions reporting at least one graduate student with primary research assistantship support during this period; this number fluctuated between 219 and 224. Since these institutions had probably been receiving research funds over the entire period, it is likely that they were supporting graduate students with research assistantships as their primary support mechanism. Thus, most of the fluctuation and the entire increase in the number of institutions reporting at least one graduate student receiving a research assistantship as their primary support mechanism occurred among comprehensive; liberal arts; two-year community, junior, and technical; and professional and other specialized schools. (See appendix table 6-47.) Only 46 percent of this group of schools reported at least one graduate student with an RA as primary support mechanism in 1980, compared to 57 percent in 1997.[59]

Throughout this period, considerably fewer institutions reported students with primary RA support financed primarily by the Federal Government than reported students with such support financed primarily from non-Federal sources. This difference is particularly pronounced among the "other" Carnegie institutions, 114 (32 percent) of which report RAs supported by the Federal Government in 1997 compared to 185 (51 percent) that report RAs financed by non-Federal sources. Why so many fewer other institutions report the Federal Government as a primary source of funds for research assistantships than receive R&D funds from the Federal Government is unclear.

[59]Percentages are calculated by dividing the number of schools reporting at least one RA into the number of schools responding to the survey. If an institution does not report any full-time graduate students with an RA as their primary support mechanism, it does not necessarily mean that the institution does not have any graduate students being supported by research assistantships. It simply indicates that the research assistantship is not the primary mechanism of support for any of the students attending that institution.

Figure 6-28.
Field distribution of full-time S&E graduate students with a research assistantship as primary support mechanism, by federal agency of primary support: 1997

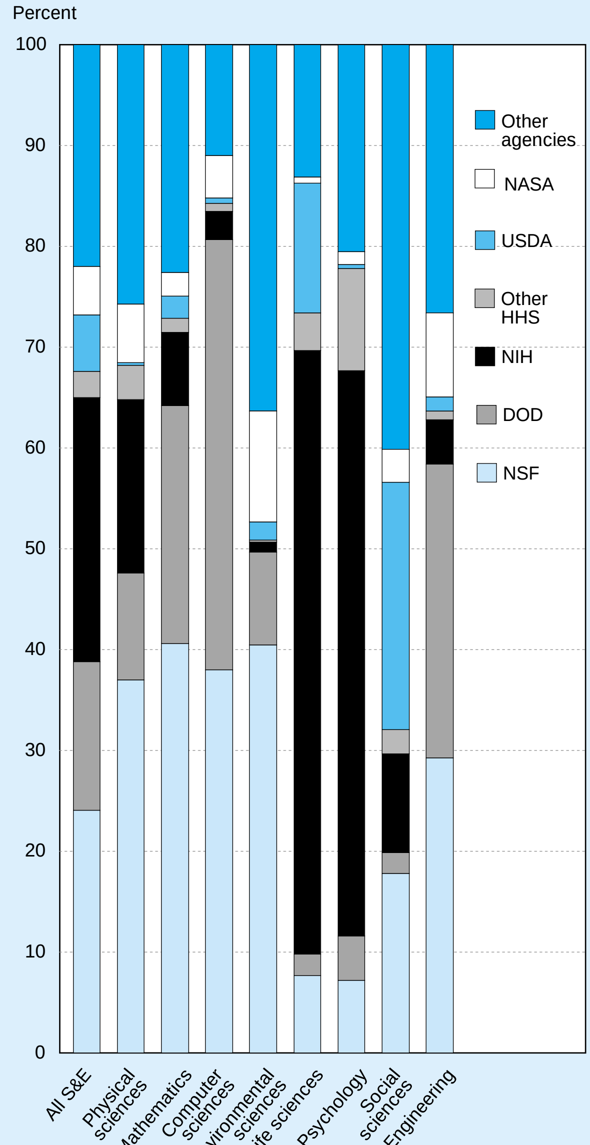


NSF = National Science Foundation; DOD = Department of Defense; NIH = National Institutes of Health: HHS = Department of Health and Human Services; USDA = Department of Agriculture; NASA = National Aeronautics and Space Administration

NOTE: The agencies cited here are the only ones for which graduate support data are reported in 1997. Life sciences also includes the health fields (medical sciences and other life sciences).

See appendix table 6-45. *Science & Engineering Indicators – 2000*

Figure 6-29.
Federal agency distribution of full-time S&E graduate students with a research assistantship as primary support mechanism, by field: 1997



NSF = National Science Foundation; DOD = Department of Defense; NIH = National Institutes of Health: HHS = Department of Health and Human Services; USDA = Department of Agriculture; NASA = National Aeronautics and Space Administration

NOTE: The agencies cited here are the only ones for which graduate support data are reported in 1997. Life sciences also includes the health fields (medical sciences and other life sciences).

See appendix table 6-46. *Science & Engineering Indicators – 2000*

The Debt Burden of New Science and Engineering Ph.D.s

Two NSF Issue Briefs (NSF 1998b and 1999c) examined the debt owed by 1993–96 science and engineering (S&E) doctorate recipients at the time of Ph.D. conferral for undergraduate and/or graduate education expenses (data do not allow them to be separated) for tuition and fees, living expenses and supplies, and transportation to and from school. Differences were highlighted in the debt situation of U.S. citizen and foreign Ph.D. recipients, among racial/ethnic groups, and between men and women.

The main findings of these studies were:

- U.S. citizens were more likely to report at least some debt, and to owe larger amounts, than were foreign students.
- Among U.S. citizens, a smaller percentage of underrepresented minority (American Indian, Alaskan Native, black, and Hispanic) S&E Ph.D. recipients were debt free compared to whites or Asians and Pacific Islanders. Among those with debt, underrepresented minorities reported higher levels of debt than their white or Asian and Pacific Islander counterparts.
- Among U.S. citizens there was little difference between the debt situation of men and women at the aggregate S&E level, but these aggregate findings actually masked some field differences in the debt situation between male and female S&E Ph.D. recipients.*

Data for 1997 S&E doctorate recipients show similar results to the earlier studies. (See text table 6-6.) Overall, just under half of those who received their S&E Ph.D.s in 1997 reported having no debt at the time of Ph.D. conferral. An additional 29 percent reported total debt burdens of $20,000 or less and another 14 percent reported debt levels exceeding $20,000.** Only 40 percent of U.S. citizen Ph.D.s reported being free of debt compared to two-thirds of those without U.S. citizenship. Nineteen percent of U.S. citizens reported debt burdens exceeding $20,000, and 37 percent reported debt of less than $20,000; for foreign Ph.D. recipients, comparable percentages were 9 and 21 percent, respectively.

Among U.S. citizens, only 28 percent of underrepresented minority S&E Ph.D. recipients reported not having any debt, compared to 41 percent for whites and 44 percent for Asians and Pacific Islanders. They also reported higher levels of debt than their white or Asian and Pacific Islander counterparts. Even though underrepresented minorities are more likely to receive their Ph.D.s in fields subject to greater likelihood and higher levels of debt (psychology and the social sciences), the aggregate differences are not primarily the result of field distribution differences. In each of the fields presented in text table 6-6, except for the environmental sciences, a smaller percentage of underrepresented minorities reported not having any debt than either whites or Asians and Pacific Islanders. In addition, in each field the percentage of underrepresented minorities reporting debt greater than $20,000 is always greater than the percentage of Asian and Pacific Islanders or whites reporting such debt.

Once again, in 1997, there was little difference at the aggregate level between the debt situation of men and women. Forty percent of each group reported having no debt. Thirty-six percent of the women reported debt less than $20,000 compared to 37 percent of the men; 20 percent reported debt exceeding $20,000 compared to 18 percent of men. However, in all but two of the fields presented in the text table—the computer sciences and the environmental sciences—a larger proportion of women reported not having any debt than did men. Some of the differences reported are substantial. Also, in most fields a smaller percentage of women than men reported debt exceeding $20,000.

*A major reason that aggregate data show similarities in the debt situation of men and women is that psychology, the field with the highest percentages and levels for educational debt, accounts for about 30 percent of women's S&E Ph.D.s compared to 10 percent of men's.

**Some respondents failed to furnish this information.

Text table 6-6.
Cumulative debt related to the education of S&E doctorate recipients, by citizenship status, sex, race/ethnicity, and field: 1997

Ph.D. field	Status	Number of Ph.D.s	Percent with: No debt	Percent with: < or = $20K	Percent with: >$20K
All S&E fields	All	28,241	47	29	14
	U.S. citizen	16,686	40	37	19
	Foreign	9,530	67	21	9
	Male (U.S. citizen)	9,948	40	37	18
	Female (U.S. citizen)	6,738	40	36	20
	Asian/Pacific Islander (U.S. citizen)	1,043	44	32	14
	White (U.S. citizen)	13,902	41	37	19
	Underrepresented minority (U.S. citizen)	1,238	28	40	27
Physical sciences	All	3,711	51	32	9
	U.S. citizen	2,112	40	43	12
	Foreign	1,376	73	19	6
	Male (U.S. citizen)	1,644	40	43	12

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Text table 6-6.
Cumulative debt related to the education of S&E doctorate recipients, by citizenship status, sex, race/ethnicity, and field: 1997

Ph.D. field	Status	Number of Ph.D.s	Percent with		
			No debt	< or = $20K	>$20K
Physical sciences	Female (U.S. citizen)	468	41	44	11
	Asian/Pacific Islander (U.S. citizen)	155	45	38	8
	White (U.S. citizen)	1,779	41	44	12
	Underrepresented minority (U.S. citizen)	106	29	43	18
Mathematics	All	1,112	58	26	7
	U.S. citizen	516	50	36	9
	Foreign	516	73	18	5
	Male (U.S. citizen)	378	48	36	11
	Female (U.S. citizen)	138	55	37	4
	Asian/Pacific Islander (U.S. citizen)	34	44	26	9
	White (U.S. citizen)	440	52	37	9
	Underrepresented minority (U.S. citizen)	22	32	32	23
Computer sciences	All	889	59	22	9
	U.S. citizen	417	58	28	10
	Foreign	403	69	18	9
	Male (U.S. citizen)	336	58	29	10
	Female (U.S. citizen)	81	58	26	10
	Asian/Pacific Islander (U.S. citizen)	42	57	29	2
	White (U.S. citizen)	337	60	28	10
	Underrepresented minority (U.S. citizen)	20	40	40	20
Environmental sciences	All	862	51	30	9
	U.S. citizen	518	46	40	11
	Foreign	281	70	16	7
	Male (U.S. citizen)	380	47	39	11
	Female (U.S. citizen)	138	42	41	12
	Asian/Pacific Islander (U.S. citizen)	18	33	50	0
	White (U.S. citizen)	458	46	41	11
	Underrepresented minority (U.S. citizen)	23	57	22	22
Life sciences	All	8,077	47	32	12
	U.S. citizen	5,032	42	39	15
	Foreign	2,539	65	23	8
	Male (U.S. citizen)	2,589	37	41	18
	Female (U.S. citizen)	2,443	47	37	12
	Asian/Pacific Islander (U.S. citizen)	314	50	30	13
	White (U.S. citizen)	4,234	42	40	15
	Underrepresented minority (U.S. citizen)	351	29	46	22
Psychology	All	3,489	25	28	32
	U.S. citizen	2,886	26	32	37
	Foreign	217	53	28	18
	Male (U.S. citizen)	944	23	30	42
	Female (U.S. citizen)	1,942	28	32	35
	Asian/Pacific Islander (U.S. citizen)	101	31	24	39
	White (U.S. citizen)	2,422	27	32	37
	Underrepresented minority (U.S. citizen)	319	19	34	40
Social sciences	All	4,049	40	32	19
	U.S. citizen	2,517	34	37	25
	Foreign	1,209	58	27	11
	Male (U.S. citizen)	1,399	32	39	24
	Female (U.S. citizen)	1,118	37	35	25
	Asian/Pacific Islander (U.S. citizen)	94	33	36	19
	White (U.S. citizen)	2,106	36	37	24
	Underrepresented minority (U.S. citizen)	222	22	44	33
Engineering	All	6,052	57	25	10
	U.S. citizen	2,688	50	34	11
	Foreign	2,989	68	20	10
	Male (U.S. citizen)	2,278	49	33	12
	Female (U.S. citizen)	410	51	37	9
	Asian/Pacific Islander (U.S. citizen)	285	45	32	12
	White (U.S. citizen)	2,126	51	34	11
	Underrepresented minority (U.S. citizen)	175	42	36	17

NOTES: Percentages do not total to 100 due to rounding and omission of nonrespondents from table. Underrepresented minorities include American Indians/Alaskan Natives, blacks, and Hispanics. Debt is for undergraduate and/or graduate education expenses for tuition and fees, living expenses and supplies, and transportation to and from school.

SOURCE: National Science Foundation, Division of Science Resources Studies, Survey of Earned Doctorates, various years, special tabulations.

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Outputs of Scientific and Engineering Research: Articles and Patents

The products of academic research include trained personnel and advances in knowledge. Trained personnel have been discussed in chapter 4 of this volume and earlier in this chapter. This section presents two sets of indicators of advances in knowledge: articles published in a set of the world's most influential refereed journals (see sidebar, "Data Sources for Article Outputs"), and patents awarded to U.S. universities and colleges.

While academic researchers contribute the bulk of all scientific and technical articles published in the United States, the focus in this section is considerably broader. It includes U.S. articles in all sectors, and total U.S. articles in the context of article outputs of the world's nations, as reflected in a set of major international scientific and technical journals whose contents are covered in the Institute of Scientific Information's (ISI) Science Citation Index (SCI) and Social Science Citation Index (SSCI).

The *output volume* of research—*article counts*—is one basic indicator of the degree to which different performers contribute to the world's production of research-based S&E knowledge. The outputs of different U.S. sectors—universities and colleges, industry, government, and nonprofit institutions—indicate these organizations' relative prominence in the United States overall and in particular S&E fields. The same indicator, aggregated by country, provides approximate information about the U.S. position in the global S&E enterprise and the emergence of centers of S&E activity.

Scientific *collaboration* in all fields increasingly crosses organizational and national boundaries. Articles with *multiple authors* in different venues or countries provide an indicator of the degree of collaboration across sectors and nations. Scientific collaboration has risen with the actions of governments to stimulate it, especially over the past decade. Cross-sectoral collaboration is viewed as a vehicle for moving research results toward practical application. International collaboration, often compelled by reasons of cost or scope of the issue, provides intellectual cross-fertilization and ready access to work done elsewhere.

The perceived *usefulness* of research results to further advancement of the state of knowledge is reflected in *citations*. Both domestic and international citation patterns will be examined. A related indicator, references to scientific and technical articles on patents, suggests the relatedness of the research to presumed practical application.

Data Sources for Article Outputs

The *article counts, coauthorship data,* and *citations* discussed in this section are based on scientific and engineering articles published in a stable set of about 5,000 of the world's most influential scientific and technical journals tracked since 1985 by the Institute of Scientific Information's (ISI) Science Citation Index (SCI) and Social Science Citation Index (SSCI). Fields in this database are determined by the classification of the journals in which articles appear; journals in turn are classified based on the patterns of their citations, as follows:

Field	Percent of journals
Clinical medicine	24
Biomedical research	11
Biological sciences	10
Chemistry	7
Physics	5
Earth and space sciences	5
Engineering and technology	8
Mathematics	3
Psychology	6
Social sciences	11
Other	10

For the first time, journals in psychology, the social sciences, and certain other applied social science fields are included in the analysis, to provide a fuller examination of all science and engineering fields. The "other" category includes ISI-covered journals in professional fields and health whose citation patterns indicate their strong links to the social sciences or psychology. Appendix table 6-48 lists the constituent subfields of the journals covered here.

The SCI and SSCI appear to give reasonably good coverage of a core set of internationally recognized scientific journals, albeit with some English-language bias. Journals of regional or local importance are not necessarily well covered, which may be salient for the engineering and technology, psychology, social sciences, and "other" categories, as well as for nations with a small or applied science base.

Articles are attributed to countries and sectors by their authors' institutional affiliations at time of authorship. Thus, coauthorship as used here refers to corporate coauthorship: a paper is considered coauthored only if its authors have different institutional affiliations. The same applies to cross-sectoral or international collaborations. For example, a paper written by an American temporarily residing in Britain with someone at her U.S. home institution is counted as internationally coauthored, thus overstating the extent of such collaborations. Likewise, an article written by a British citizen temporarily located at a U.S. university with a U.S. colleague would not be counted as internationally coauthored, thus understating the count.

All data presented here derive from the Science Indicators database prepared for NSF by CHI Research, Inc. The database *excludes* all letters to the editor, news pieces, editorials, and other content whose central purpose is not the presentation or discussion of scientific data, theory, methods, apparatus, or experiments.

Finally, *patents issued to U.S. universities* will be examined. They provide another indicator of the *perceived utility* of the underlying research, with trends in their volume and nature indicating the universities' interest in seeking commercialization of its results.

U.S. Articles: Counts, Collaboration, and Citations

The complexity and breadth of a nation's science and engineering infrastructure is frequently described in terms of the financial resources it consumes and its personnel base. Article outputs provide another indicator that is particularly well suited to the mapping of the basic and applied research activities carried out in the United States—that is, activities for which articles are often the prime output. What is the contribution of scientists and engineers in the different sectors to the production of U.S. research articles, and in what fields?

All U.S. sectors contribute to the published, refereed science and technology (S&T) literature, albeit in different proportions, with academia providing the bulk of the article output. During 1995–97, an annual average of 173,200 articles were published by U.S. authors in a set of scientific and technical journals covered by the Science and Social Science Citation Indexes since 1985. (See appendix table 6-49.) Over the period, academic researchers contributed almost three-fourths of the total output; industry, the Federal Government, and the nonprofit sector (mainly health-related organizations publishing in life sciences fields) contributed 7–8 percent each. The output of federally funded R&D centers (FFRDCs) added another 3 percent to the total. (See figure 6-30 and appendix table 6-50.)

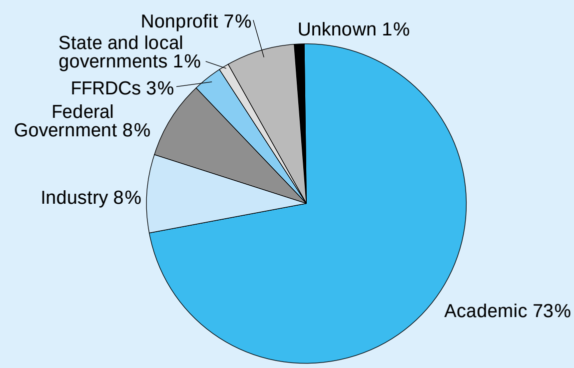
More than half of this U.S. portfolio of scientific and technical research articles—55 percent—covered subjects in the life sciences; another 26 percent dealt with physical sciences, earth and space sciences, and mathematics; 6 percent with engineering and technology; and the remainder with the social and behavioral sciences, including health and professional fields with close ties (based on citations) to the latter two fields. (See figure 6-31.)

Different sectors have different relative emphases. In the portfolios of academia, government, and nonprofit institutions, articles in life sciences fields are prominent, especially in clinical medicine and biomedical research. Industry articles focus on clinical medicine, physics, chemistry, and engineering and technology, with a growing emphasis on the life sciences. FFRDC articles focus on physics, chemistry, earth and space sciences, and engineering and technology. (See appendix tables 6-49 and 6-50.)

Viewed across all performer sectors, little change is evident in the field distribution of these articles—earth and space science registered marginal gains, as did biomedical research and clinical medicine, while biology lost some ground. Likewise, the overall contribution of the different sectors has changed little, except for a marginal percentage-point gain of academia offsetting a marginal decline in industry's share. However, over the 1988–97 decade, some changes in the field mix within specific sectors are worthy of note:

- Among *industry articles*, the number of physics articles declined by half during the 1990s, causing their share to decline steeply, from 21 percent a decade ago to less than 15 percent. Article volume in clinical medicine and biomedical research rose by 20 percent, bringing about share gains from 18 to 24 percent and from 10 to 13 percent, respectively. These numbers clearly indicate a shift in publishing activity (though not necessarily R&D—see chapter 2) from traditional physical-sciences- and engineering-oriented industry segments toward those in pharmaceuticals and other life-science-related areas. (See appendix table 6-49.)

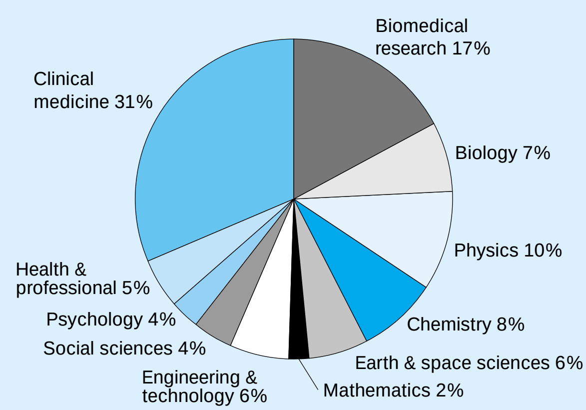
Figure 6-30.
Distribution of U.S. scientific and technical articles, by sector: 1995–97



FFRDC = Federally Funded Research and Development Center

See appendix table 6-50. *Science & Engineering Indicators – 2000*

Figure 6-31.
Distribution of U.S. scientific and technical articles, by field: 1995–97



See appendix table 6-49. *Science & Engineering Indicators – 2000*

- Changes in *academia's portfolio* were more gradual, showing gains of 1 percentage point each in physics, earth and space sciences, and biomedical research publications, with declines in biology and the social sciences. (See appendix table 6-49.)

- The *Federal Government's output* showed mixed trends. The relative balance of in-house articles shifted modestly toward physics and earth and space sciences, with some decline in clinical medicine and biology. However, among articles from university-affiliated FFRDCs, the share of physics papers fell by nearly 3 percentage points, accompanied by a growing share for earth and space sciences articles. (See appendix table 6-49.)

Scientific Collaboration

Developments in science and engineering have led to broader collaboration among researchers. As the scale, cost, and complexity of attacking many problems have increased, research teams have become common, changing the structure of the research. Single-investigator work, as evidenced by single-author publications, is in decline in virtually all fields. The Federal Government has long sought to stimulate this trend, for example, by promoting collaboration across sectors: for example, industry-university or FFRDC-industry activities. (See chapter 2.) Such cross-sector collaboration is seen as enriching the perspectives of researchers in both settings, and as a means for more efficiently channeling research results toward practical applications.

Two trends predominate in the collaborative activities of U.S. researchers:

- strong cross-sectoral collaboration, and

- increasing international collaboration.

The proportion of U.S. scientific and technical articles with multiple institutional authors has continued to rise. In 1997, 57 percent of all S&E articles had multiple authors, up from 49 percent a decade earlier. This resulted from a falling number of U.S. single-author articles, accompanied by a rise in the number of multi-author articles. This general pattern held for all but mathematics, psychology, and the social sciences, where falling single-author output was accompanied by static counts of multi-author papers. (See appendix table 6-51.) Coauthorship was highest in clinical medicine, biomedical research, earth and space sciences, and physics (ranging from 59 to 66 percent), lowest in the social and behavioral sciences and chemistry (from 36 to 44 percent).

The bulk of the increase in corporate[60] coauthorship of U.S. articles reflected rising international collaboration. By the mid-1990s, nearly one article in five—18 percent—had at least one non-U.S. author, up from 12 percent at the beginning of the decade. Physics, earth and space sciences, and mathematics had the highest rates of international coauthorship, ranging from 27 to 30 percent of all U.S. articles. International collaboration rates were much lower in the social and behavioral sciences—9–10 percent. (See appendix table 6-51.)

Academia was at the center of cross-sector collaborations in every sector and field. Coauthorship rates with academia—the percentage of a sector's coauthored papers with an academic collaborator—were above 70 percent for the Federal Government, university-managed FFRDCs, and nonprofit institutions. For other sectors, they ranged from 59 percent for industry-managed FFRDCs to 66 percent for industry itself. In mathematics, 80–90 percent of cross-sector collaborations were with authors in higher education institutions, underlining the key role of academia in mathematics research, where 93 percent of U.S. articles in that field are published. (See appendix table 6-52.)

Other collaborative patterns vary by field, depending on different sectors' relative strengths and foci. For the industry sector, joint work with the Federal Government was prominent in earth and space science, as was collaboration with nonprofit authors in clinical medicine and biomedical research. For the Federal Government, industry collaboration in physics, chemistry, earth and space sciences, and engineering and technology was prominent, as were university-managed FFRDCs in earth and space sciences. The nonprofit sector's collaborations focused heavily on academia and the Federal Government, except in engineering and technology, where nearly one-third of cross-sector articles were coauthored with industry researchers. (See appendix table 6-52.)

Academic scientists had strong collaborative ties with industry in physics, chemistry, mathematics, and engineering and technology (ranging from 31 to 55 percent of academic cross-sector collaborations in these fields). More than half of academia's cross-sector articles in biology had Federal Government authors, while collaboration with nonprofit institutions was heavy in clinical medicine and biomedical research (44 and 38 percent, respectively), in the social and behavioral sciences (48 and 42 percent, respectively), and in the health and professional fields (37 percent). In the physical sciences, academic collaboration with authors in university-managed FFRDCs was pronounced. (See appendix table 6-52.)

Citations

In their articles, scientists cite prior research on which their own work builds. These citations, aggregated by field and sector, provide a rough indicator of the use of these articles by researchers working in different sectors.

The distribution of citations to U.S. scientific and technical articles largely—but not entirely—reflects that of the articles themselves, with the bulk of citations going to academic papers. Citation to same-sector articles generally exceeded sector shares, only somewhat for the dominant academic publishing sector, three- to fourfold for most other sectors, tenfold for articles from FFRDCs. The share of citations from each of these sectors to academic publications grew over the decade. (See appendix table 6-53.)

The academic sector received 72 percent of all 1994–97 U.S. citations. Its share of citations in chemistry, engineering

[60]Throughout the chapter, coauthorship refers to *corporate* coauthorship: that is, joint authors with different institutional affiliations. See sidebar, "Data Sources for Article Outputs," above.

and technology, and the social sciences exceeded the sector's share of U.S. articles in these fields.[61] Differences between academic article and citation shares in other fields were generally minor. For other sectors and fields, the relative citation volume was generally what would be expected on the basis of output shares. Exceptions were higher-than-expected biomedical research citations to nonprofit sector publications, and lower-than-expected citation frequency of industrial articles in chemistry and engineering and technology. (See appendix tables 6-50 and 6-53.)

Care must be taken to avoid misinterpretation of these differences: they are not indicators of quality differentials. In ongoing research, basic research will tend to be cited with relatively greater frequency than applied research. To the extent that industry articles tend to be less basic than those from academia, the comparison of article output and citation shares is a very rough one indeed.

Linkages Among Disciplines

Research on many challenging scientific problems draws on knowledge and perspectives of a multitude of disciplines and specialties. Citations in scientific and technical articles that cross disciplinary boundaries are one indicator of the multidisciplinary nature of the conduct of research. Of course, frequency of citations only hints at how essential a particular piece of work was to the research being reported. The indicator used here is relatively weak, because of its reliance on a journals-based field classification. Data for other, stronger indicators of multidisciplinary research activities are not readily available: collaboration of researchers across disciplinary boundaries, multidisciplinary centers, and major multidisciplinary projects—for example, global climate research—lack readily available representative data. Nevertheless, cross-disciplinary citations do provide an insight into connections among major fields and fine fields. They demonstrate the relevance to progress in a given field of advances in a range of other fields.

Citations in U.S. articles published in 1997 were aggregated by field.[62] There were approximately 1.3 million such references: 71 percent to the life sciences; 22 percent to mathematics, the physical, and earth and space sciences combined; 5 percent to the social and behavioral sciences and related health and professional fields combined, and just under 2 percent to engineering. (See appendix table 6-54.)

The distribution of citations across broad fields shows the expected concentration of references to articles in the same broad field. Biology and engineering have the lowest rates of self-citation (in this broad-field sense): 62 percent each. Physics and the earth and space sciences have the highest rates: 82 and 83 percent, respectively. Citations in life sciences articles—biology, biomedical research, and clinical medicine—were particularly heavily focused on these three fields: 92 percent of all citations in biology, 97 percent of those in biomedical research, and 98 percent of those in clinical medicine were to articles in the life sciences. A greater proportion of citations in the other sciences and engineering focus on the life sciences fields than vice versa. (See appendix table 6-54.)

Examination of fine fields generally underscores the tight connection among the life science fields, but also reveals the strength of their connections which extend into other fields. For example, one-fifth of all citations in marine and hydrobiology are to fields outside the life sciences, particularly to earth and space sciences and physical sciences. In clinical medicine, nearly one-fifth of the citations found in articles on addictive diseases are to articles in the behavioral and social sciences and related health and professional fields. Especially strong links to fields outside the life sciences also characterize agricultural and food sciences, ecology, biomedical engineering, biophysics, microscopy, pharmacy, and environmental and occupational health.

Citations for the physical and earth and space sciences show strong links to other physical science fields, engineering, and especially to biomedical research. The social and behavioral sciences are linked among themselves but also to specific areas in clinical medicine, biomedical research, and biology. (See appendix table 6-54.)

International Article Production: Counts, Collaboration, and Citations

The world's key scientific and technical journals exercise a degree of quality control by requiring articles submitted for publication to undergo peer review. Thus, the volume of different countries' articles in these peer-reviewed journals is a rough indicator of their level of participation in the international S&T arena. In addition, the distribution of their articles across fields reveals national research foci.[63]

Worldwide publication of scientific and technical articles averaged about 515,700 per year during 1995–97, a 12 percent increase over the 1986–88 period.[64] The largest category, clinical medicine, accounted for 29 percent of the total, about the same as for physics and chemistry combined; biomedical research (15 percent), biology, and engineering and technology (7 percent each) accounted for the bulk of the remainder. (See figure 6-32 and appendix table 6-55.) Note that this field distribution differs from that of the United States shown in figure 6-31—it is lower in the life sciences areas and distinctly higher in physics and chemistry.

Over the 1995–97 period, five nations produced approximately 62 percent of the articles published in the 1985 SCI set of journals: the United States (34 percent), Japan (9 per-

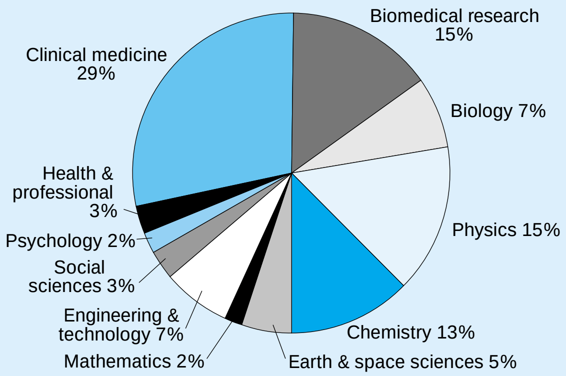
[61]The comparison made here is based on the 1989–94 publications data in appendix table 6-50.

[62]Specifically, citations in 1997 U.S. articles covered in the ISI Science and Social Science Citation Indexes to articles published in 1993–95.

[63]The numbers reported here are based on the 1985 ISI set of core journals, to facilitate comparisons over the countries. Counts are fractional: an article with multinational authors is assigned to the participating countries in proportion to their share of authors. Percentages reflect fractional counts. This set of influential world S&T journals has some English language bias but is widely used around the world. See for example Organization of American States (1997) and European Commission (1997). Also see sidebar, "Data Sources for Article Outputs" in this chapter.

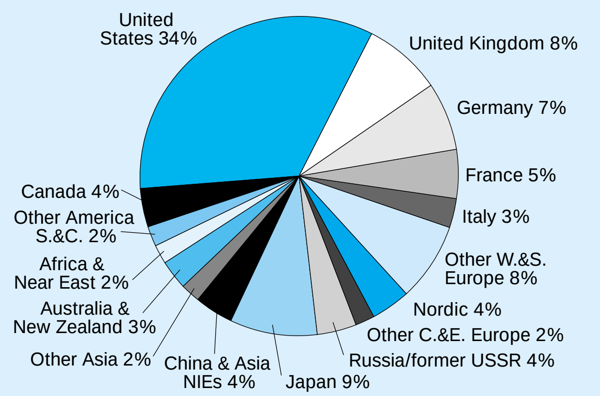
[64]This is a minimum estimate: an expanded 1991 journal set yields a slightly higher growth rate for the 1990s.

Figure 6-32.
Distribution of the world's scientific and technical articles, by field: 1995–97



See appendix table 6-55. *Science & Engineering Indicators – 2000*

Figure 6-33.
Distribution of the world's scientific and technical articles in major journals, by region/country: 1995–97



NIE = newly industrialized Asian economics

See appendix table 6-56. *Science & Engineering Indicators – 2000*

cent), the United Kingdom (8 percent), Germany (7 percent), and France (5 percent).[65] No other country's output reached 5 percent of the total. (See figure 6-33.) These countries possess relatively large and wealthy economies, extensive scientific and technical infrastructure, and large pools of scientists and engineers,[66] which undergird their continuing large share of the world's scientific and technical publications (as captured in the ISI database). Nevertheless, the five countries' collective proportion of the world's article output declined slightly over the past decade, from 64 percent in 1986–88 (and from 38 percent for the United States). This trend reflected the development or strengthening of scientific capabilities in several countries and world regions—in Asia and Southern Europe—following the end of the Cold War. (See appendix table 6-56.)

Over the last decade, the article share of Western and Southern European countries rose from 31 to 35 percent, reaching a level similar to that of the United States. It is likely that these gains reflect, at least in part, these nations' concerted policies to strengthen the science base in individual countries and across Europe as a whole.[67] The article volume of the Central European states as a group—Bulgaria, the Czech Republic, Hungary, Poland, Romania, and Slovakia—declined somewhat through the early 1990s, but by 1995–97 it had rebounded to 10,400 articles, slightly above its 1986–88 level. In contrast, the output for the nations of the former Soviet Union declined during the 1990s, dropping from about 31,200 in 1986–88 to 26,600 in 1992–94 and further to 22,200 in the 1995–97 period. This numerical decrease led to a decline in world share from 7 to 4 percent; especially sharp drops occurred in clinical medicine and biomedical research. The ongoing decline in these countries' output during the 1990s points to continuing difficulties that affect their scientific activity. (See appendix tables 6-55 and 6-56.) These trends roughly parallel those in R&D spending in the region (see chapter 2), especially in Russia, which experienced large decreases over the period.

Recent economic problems notwithstanding, Asia has emerged as a potent high-technology region.[68] Its output of scientific and technical articles in refereed journals grew rapidly over the past decade, providing evidence of a robustly developing indigenous S&E base. From 1986–88 to 1995–97, the Asian nations' world share of publications rose from 11 to 14 percent, amid contradictory trends. Japan's output rose 35 percent, while China's more than doubled; that of the four newly industrialized Southeast Asian economies—Taiwan, South Korea, Singapore, and Hong Kong—more than quadrupled, accounting for more than one-third of the continent's entire net increase. However, India's output continued to decrease, a matter of concern to that nation.[69] (See appendix tables 6-55 and 6-56.)

The conduct of research reflected in these article outputs requires financial, physical, and human resources. The empirical relationship between the size of a nation's

[65]Totals do not add because of rounding.

[66]Also see chapter 2, "U.S. and International Research and Development: Funds and Alliances"; chapter 4, "Higher Education in Science and Engineering"; and chapter 7, "Industry, Technology, and the Global Marketplace."

[67]These include five-year Framework Programmes of the European Union (EU), EU funding provided through Structural Funds, Community Initiatives Programmes, and efforts outside the EU framework such as EUREKA, a program to stimulate industry-university-research institutes partnerships. See NSF (1996b) for a brief discussion, European Commission (1997) for a fuller treatment.

[68]See NSF (1993 and 1995a). Also see chapter 2, "U.S. and International Research and Development: Funds and Alliances"; chapter 4, "Higher Education in Science and Engineering"; and chapter 7, "Industry, Technology, and the Global Marketplace."

[69]See Raghuram and Madhavi (1996). The authors note that this decline cannot be attributed to journal coverage in the SCI, and that it is paralleled by a decline in citations to Indian articles. They speculate that an aging scientific workforce may be implicated, along with a "brain drain" of young Indian scientists whose articles would be counted in the countries in which they reside, not in their country of origin.

economy—its gross domestic product (GDP)—and its article output volume is moderately high.[70] (See figure 6-34.) Clearly, however, some countries produce output well in excess of what would be expected, based on raw economic size. (See appendix table 6-57.) For example, Israel, the Nordic countries, Switzerland, and New Zealand rank particularly high; the United States is in the middle range. Nations with fast-developing economies tend to have smaller-than-expected article outputs, based on their estimated GDPs.

The Science and Technology Portfolios of Nations

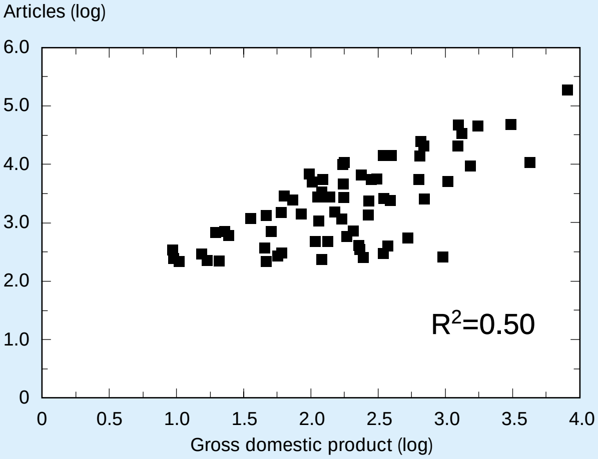
Nations make implicit or explicit choices about the nature of their science and technology portfolios through the allocation of resources; the results of these choices are roughly reflected in their article output data. It is clear that different nations have very different choice patterns, and also that these patterns can—and do—change over time.[71] (See appendix table 6-58.)

Figure 6-35 shows the 1995–97 portfolio mix of selected countries, arrayed by the fraction of their total output devoted to the life sciences (which account for about half of these articles worldwide). The differences in emphasis are striking. Europe's Nordic countries and many of Western Europe's smaller nations heavily emphasize the life sciences.

[70] The correlation of a nation's estimated GDP and number of articles in the ISI database produces an r^2 of 0.50. Because both GDP and number of articles are highly unevenly distributed, their logarithms have been used in this calculation.

[71] See also the discussion in chapter 4, "International Comparison of First University Degrees in S&E," on the field distributions of S&E degrees of various nations.

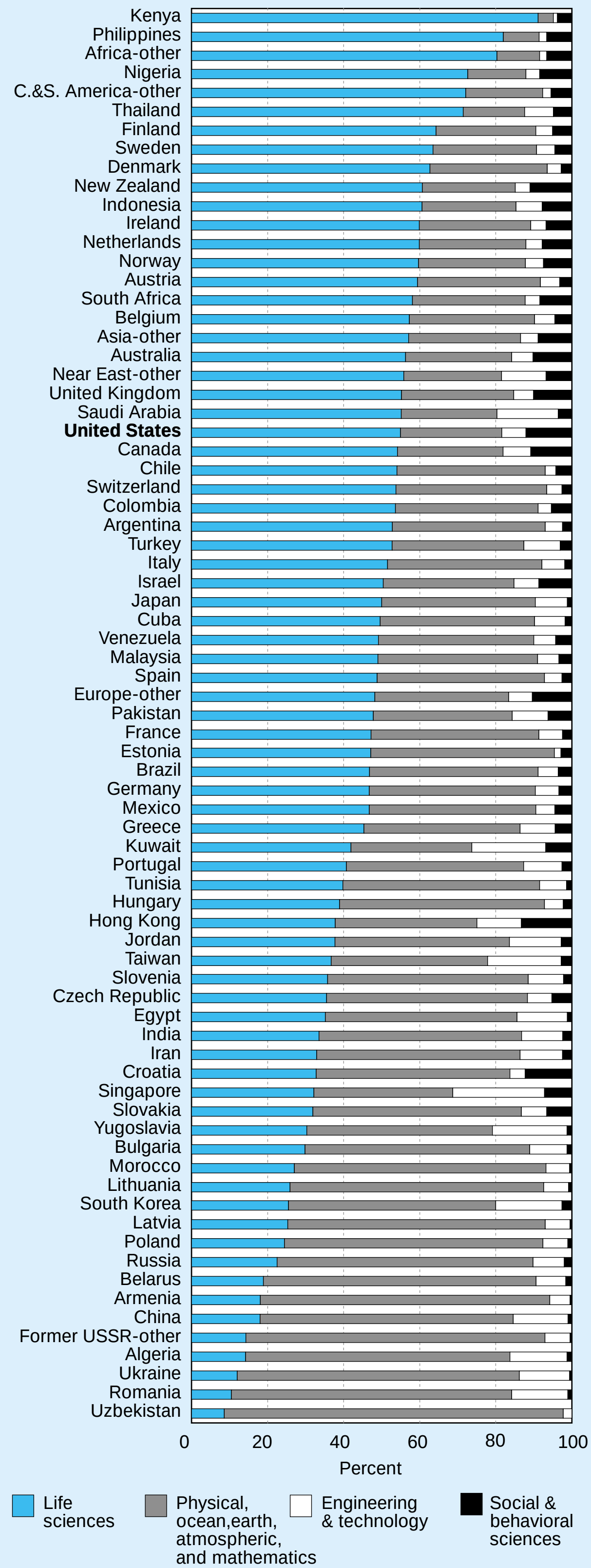
Figure 6-34.
Relationship of volume of scientific and technical articles to gross domestic product for selected countries: 1997



NOTE: Pearson correlation coefficient based on log-normalized article counts and gross domestic product.

See appendix table 6-57. *Science & Engineering Indicators – 2000*

Figure 6-35.
Distribution of selected countries' scientific and technical articles, by aggregated fields: 1995–97



See appendix table 6-58. *Science & Engineering Indicators – 2000*

China and Asia's newly industrializing economies emphasize the physical sciences and engineering and technology. The focus of Central and Eastern European nations and states of the former Soviet Union—reflecting historical patterns—rests heavily on the physical sciences. The world's biggest article-producing nations fall along a broad middle range: the United States, Canada, and the United Kingdom with slightly greater-than-average weight on the life sciences, Italy and Japan near the world average, and France and Germany weighted somewhat more toward the physical sciences. (See figure 6-35.)

Countries may shift the focus of their scientific activities. (See appendix table 6-59.) Since 1986–88, a large number of countries have increased their relative emphasis on physics while to some extent shrinking the shares of clinical medicine and, to a lesser extent, the other life sciences fields. Note that declining shares resulted sometimes, but not always, from falling absolute numbers of publications; in other instances, they reflected differential growth patterns. Perhaps not surprisingly, nations with long-established, large S&T systems exhibited greater stability in the field distribution of their articles than developing nations. Two things must be noted, however. First, the field designations used here are very broad, possibly obscuring larger changes even in the highly developed nations' portfolios. Second, moderate numerical shifts in low-volume countries' outputs can result in relatively large percentage changes across fields.

International Scientific Collaboration

Cutting-edge science in many fields increasingly involves a broad range of knowledge, perspectives, and techniques that extend beyond a given discipline or institution. This has generated increasing collaboration across disciplinary and institutional boundaries. Moreover, the scope, cost, and complexity of some of today's scientific problems (for example, mapping the human genome, constructing a coordinated array of widely spaced detection devices, or studying global environmental trends) invite—often even compel—international collaboration. In addition, developments in information technology reduce some of the geographic barriers to collaboration. For established scientific nations, this offers various benefits, including cost savings, the potential for faster progress, the application of different approaches to a problem, and the ability to stay abreast of information developed elsewhere. For nations with smaller or less-developed science and technology systems, it is a means of boosting the capabilities of their indigenous S&T base.

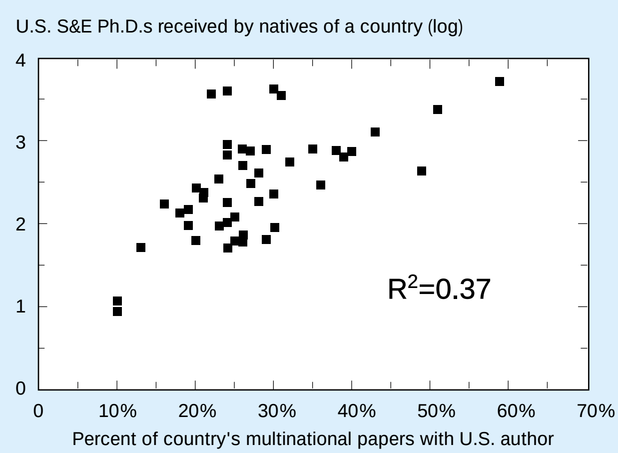
The past decade was marked by vigorous increases in international collaboration, as indicated by multicountry authors of scientific and technical articles. This phenomenon can be observed for every field and for most countries. From 1986–88 to 1995–97, the total number of articles in the ISI databases increased by 12 percent; coauthored papers rose by 46 percent (from an average of 177,100 to 258,500); and internationally coauthored articles increased by almost 115 percent (from 35,700 to 76,200). In 1995–97, half of the world's papers were coauthored (in the multi-institution sense), and 15 percent (30 percent of all coauthored articles) were written by international teams.[72] (See appendix table 6-60.) A web of intergovernmental agreements has developed that invites or requires multinational participation in some research activities. But the rise in international collaboration also appears to reflect the extent of advanced training students receive outside their native countries.[73] Figure 6-36 displays this relationship for the United States.

The incidence of coauthorship varied by field. In the United States in 1995–97, an average of 57 percent of all articles were coauthored. Clinical medicine was well above that with 66 percent; chemistry, engineering and technology, biology, mathematics, and the social and behavioral sciences had lower rates. (See appendix table 6-60.) Similar patterns are evident in many countries, suggesting field-specific publishing behaviors. In *international* collaboration, physics and earth and space sciences rank especially high; for some countries, mathematics also well exceeds the average, for others, biomedical research.

[72]The international coauthorship percentage for the world's papers appears low—15 percent—when compared to that of most individual countries, due to a counting artifact. *National* rates are based on total counts: each collaborating country is assigned one paper—that is, a paper with three international coauthors may contribute to the international coauthorship of three countries. However, for the world category, each internationally coauthored paper is counted only once. (In 1997, an average of 2.22 countries were involved in each internationally coauthored paper.)

[73]See chapter 4, "Higher Education in Science and Engineering."

Figure 6-36.
Relationship of volume of U.S.-coauthored multinational articles to U.S. S&E Ph.D.s received by natives of foreign authors' countries



NOTE: Articles published in 1991–95; Ph.D.s awarded in 1986–90.

SOURCES: Articles: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, special tabulation. Ph.D.s: National Science Foundation, Survey of Earned Doctorates.

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Who Collaborates With Whom?

Patterns of international coauthorship provide one indicator of the extent of collaborative ties among nations. By this indicator, the United States' position in international collaboration was characterized by two trends:

- From 1986–88 to 1995–97, most nations had increasing *numbers* of articles with at least one U.S. author.
- But the U.S. *share* of all their internationally coauthored articles declined.[74]

International scientific collaboration, as measured by the percentage of a country's multi-author articles involving international coauthorship, centers to a considerable degree on the United States. (See figure 6-37.) Worldwide, 44 percent of all internationally coauthored papers published in 1995–97 had at least one U.S. author. In that period, with few exceptions, from 25 to 33 percent of European countries' internationally coauthored papers involved collaboration with the United States.[75] For major science-producing Asian nations, coauthorship with U.S. researchers ranked higher. Japan and India—both nations with relatively low overall rates of international collaboration—shared 46 and 40 percent, respectively, of their internationally coauthored articles with United States researchers. Collaboration rates of other major article-producing Asian nations with the United States ranged from a high of 70 percent for Taiwan to a low of 31 percent for Singapore. China's rate was 33 percent (30 percent for Hong Kong)—but down sharply from 51 percent a decade earlier. For major South and Central American countries, rates ranged from 34 to 46 percent. The countries of Central Europe (except Hungary) and, especially, those of the former Soviet Union had lower rates of collaboration with the United States. (See appendix table 6-61.[76])

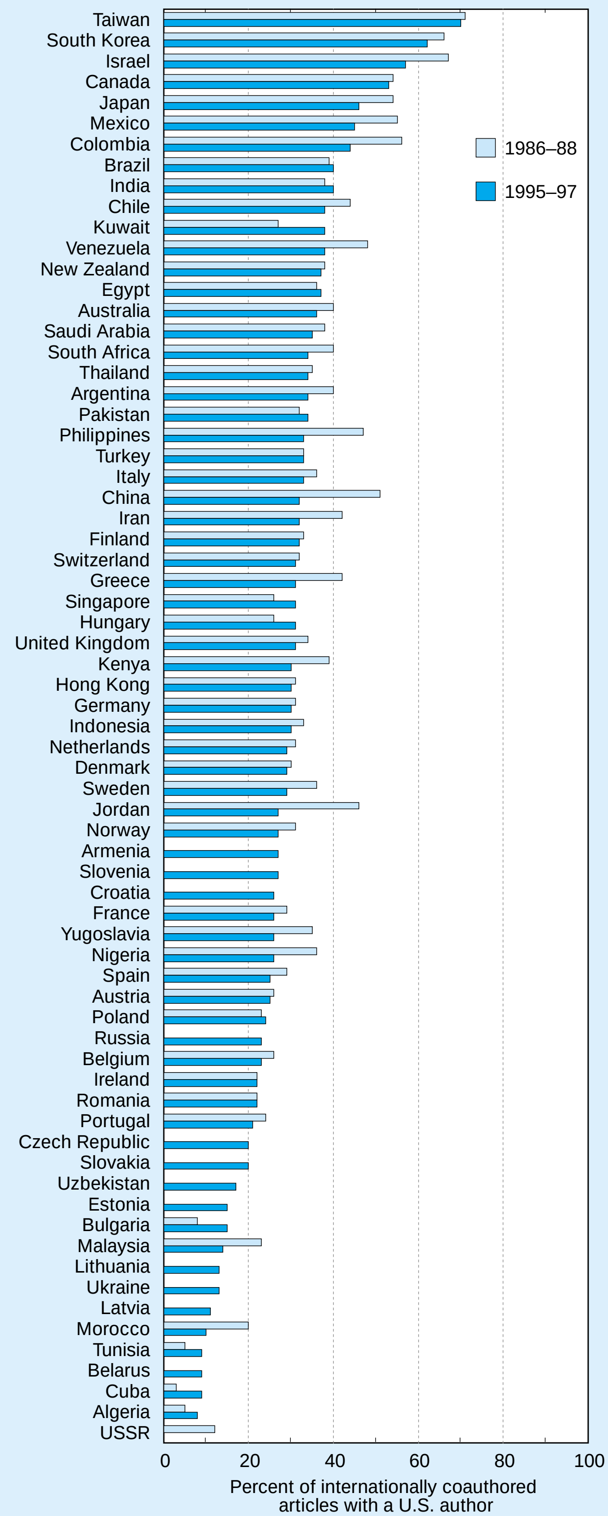
Comparison of these data with 1986–88 shows that, for most nations, the number of papers authored collaboratively with U.S. researchers rose strongly over the decade; however, the U.S. share of internationally coauthored articles declined from 51 to 44 percent of the world's total. This pattern—rising numbers of U.S. coauthored articles accompanied by declining U.S. shares—held for most countries, as they broadened the range of their international partnerships. In general, the higher the initial degree of collaboration with the United States, the greater the U.S. drop in collaboration share ($r^2 = 0.26$). Some examples (in percentage point terms): China, 19 percentage points; Israel and Mexico, 10 percentage points each; Japan, 8 percentage points; and 6 percentage points each for Chile and Argentina. (See appendix table 6-61.) These

[74]The first data column in appendix table 6-61 provides the percentages that U.S.-coauthored articles represent in a given country's internationally coauthored papers.

[75]These percentages are based on total article counts: a paper with one author each in two countries is counted as one article in each of the countries.

[76]The table is read as follows: The distribution of a given country's international collaborations with others is read along the rows. The prominence of a given country's coauthors in other countries' literatures is read down the columns.

Figure 6-37.
Percentage of internationally coauthored articles involving one or more U.S. authors for selected countries: 1986–88 and 1995–97



SOURCE: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; NSF, special tabulation

See appendix table 6-61. *Science & Engineering Indicators – 2000*

data suggest that new centers of activity and patterns of collaboration are evolving.

In the Asian region, the main trend indicates the development of regional collaborative patterns involving—especially—China and the newly industrialized economies. Overall, intraregional collaboration increased from 15 percent of all Asian foreign collaborations in the late 1980s to 24 percent a decade later. Regional collaboration rates—measured by the proportion of internationally coauthored articles published in 1986–88 and 1995–97 with an author from another Asian country—are shown in text table 6-7.

Text table 6-7 shows large increases in the overall number of articles, and of internationally coauthored articles, for a number of Asian countries, along with a rise in intra-Asian collaboration. For China, intra-Asian collaboration rose from 16 to 35 percent of its internationally coauthored papers (for Hong Kong from 25 to 47 percent) and for Singapore from 19 to 37 percent. However, regional collaboration remained relatively low for Japan, India, and Pakistan—12–15 percent of their internationally coauthored articles. Intra-Asian collaboration of Taiwan and South Korea—21 and 29 percent, respectively—was hardly changed since the mid-1980s.

Intraregional ties among the Central European states remain modest; in 1995–97 they shared 5 to 15 percent of their internationally coauthored articles. The bulk of their collaborations—roughly half for most nations—were with countries in the north, west, and south of Europe. Ties to the countries of the former USSR generally dwindled during the 1990s. Collaboration with U.S. scientists ranged from 14 to 27 percent and 31 percent for Hungary. (See appendix table 6-61.)

The collaborative ties of most countries of the former Soviet Union centered on Russia, Germany, and the United States. Almost one-half of Russia's coauthorships were with Germany and the United States, split evenly. Other major former constituent states—Ukraine, Belarus, Uzbekistan, and Armenia—shared 26–43 percent of their collaborations with Russia, and similarly large fractions with Germany and the United States combined. The Baltic nations have lower collaborative ties with Russia—11–17 percent. They have developed strong collaborative ties to the Nordic states, in particular to Finland and Sweden, reflecting the reestablishment of historical cultural and regional ties. (See appendix table 6-61.)

United States researchers partner with authors in a very large number of countries. In 1995–97, they collaborated with colleagues in more than 170 nations. German researchers were coauthors of 13 percent of U.S. internationally coauthored articles, and investigators from Canada and the United Kingdom of 12 percent each. Seven to 10 percent had authors from Japan, France, and Italy, respectively. The Netherlands, Switzerland, Israel, and Australia, with about 4 percent each, rounded out the top 10 collaborating nations.

The scope of different countries' collaborative ties with other nations can be seen in text table 6-8. It shows the total number of countries with any collaborating nondomestic author on a given nation's papers. The table reveals a dramatic expansion of cross-national collaboration over a mere decade. Virtually all countries expanded the number of nations with which they have some coauthorship ties, and a number of Asian nations more than doubled them.

Figure 6-38 shows the number of countries which shared at least one percent of their internationally coauthored articles with a given nation. The sharp drop-off in number of countries illustrates the practice of nations with relatively restricted S&T establishments to concentrate their collaborations in a relatively few countries. These smaller countries also tend to have higher levels of international coauthorship, as a percentage of their total article output, than do those with larger,

Text table 6-7.
Intra-Asian research collaboration—coauthorships among Asian countries: 1986–88 and 1995–97

	Number of articles		Internationally coauthored		Intra-Asia coauthored	
	1986–88 (sum)	1995–97 (sum)	1986–88 (sum)	1995–97 (sum)	1986-88 (sum)	1995–97 (sum)
Japan	101,553	142,548	8,259	21,608	1,009	3,308
China	11,480	27,706	2,626	7,982	415	2,808
Hong Kong	1,518	6,741	333	2,694	83	1,253
South Korea	2,338	14,091	686	3,892	191	1,139
India	29,492	28,520	2,791	4,473	244	684
Taiwan	3,807	15,874	754	2,813	157	599
Singapore	1,344	3,874	318	1,147	62	423
Thailand	1,019	1,552	493	976	134	381
Indonesia	328	732	215	631	57	277
Malaysia	722	1,292	249	554	70	270
Philippines	542	695	247	454	96	219
Pakistan	695	998	237	420	22	49

NOTE: Internationally coauthored articles with authors from at least two Asian countries. Papers are counted in each author's country.

SOURCES: Institute for Scientific Information, Science Citation Index and Social Science Citation Index; CHI Research, Inc., Science Indicators database; and National Science Foundation, special tabulation.

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Text table 6-8.
Breadth of international coauthorship ties for selected countries: 1986–88 and 1995–97

Country	Number of countries 1986–88	Number of countries 1995–97	Country	Number of countries 1986–88	Number of countries 1995–97
United States	142	173	Malaysia	32	76
United Kingdom	121	163	Chile	42	76
France	116	157	Ireland	47	76
Germany	116	147	Philippines	44	75
Canada	101	136	Greece	47	75
Netherlands	88	133	Saudi Arabia	40	75
Switzerland	92	131	Colombia	32	72
Italy	94	128	Portugal	35	71
Belgium	81	128	Morocco	30	70
Sweden	90	127	Bulgaria	38	70
Japan	80	127	Romania	38	69
Australia	84	126	Taiwan	34	67
Spain	62	118	Singapore	42	65
Brazil	66	114	Venezuela	37	60
Denmark	73	111	Algeria	24	59
India	87	109	Kuwait	36	57
China	54	107	Cuba	29	56
South Africa	58	100	Pakistan	40	53
Austria	58	99	Iran	23	49
Israel	58	98	Tunisia	21	48
Norway	53	96	Jordan	22	46
Finland	58	94	Czechoslovakia	49	NA
Thailand	49	94	Czech Republic	na	90
Mexico	54	89	Slovakia	na	68
Hungary	54	89	USSR	61	NA
Poland	57	86	Russia	na	106
Turkey	31	85	Ukraine	na	70
Egypt	63	85	Belarus	na	55
Indonesia	39	84	Armenia	na	46
New Zealand	57	83	Lithuania	na	46
South Korea	33	83	Estonia	na	45
Hong Kong	35	82	Latvia	na	37
Kenya	52	81	Yugoslavia	56	60
Nigeria	57	77	Slovenia	na	67
Argentina	47	77	Croatia	na	58

NA = not applicable; na = not available

NOTE: Number of countries with which country indicated shares any coauthored articles. Countries of the former Soviet bloc and Yugoslavia shown at end of table.

SOURCES: Institute for Scientific Information, Science Citation and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, special tabulations.

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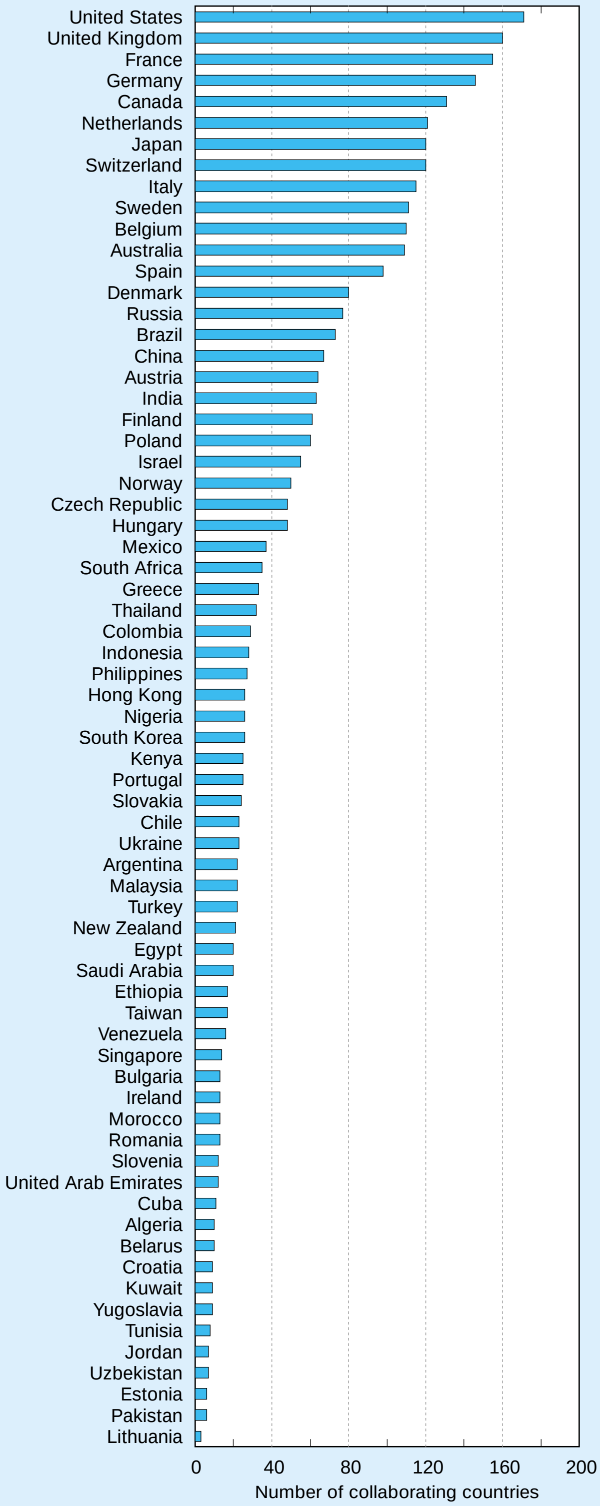
more mature systems. Rather than collaborating regionally, scientists from developing nations tend to work with those from major science-producing nations—in part based on student-mentor ties, as illustrated earlier by figure 6-36 for the United States.

International Citations to Scientific and Technical Articles

The global dimensions of the conduct of scientific activity, discussed above in terms of international research collaboration, are also reflected in the patterns of citations to the literature. Scientists and engineers around the world cite prior work done elsewhere to a considerable extent, thus acknowledging the usefulness of this output for their own work. Citations to one's own country's work are generally prominent and show less of a time lag than citations to foreign outputs. Regional citation patterns are evident as well, but citations to research outputs from around the world are extensive. Citations, aggregated here by country and field, thus provide an indicator of the perceived utility of a nation's science outputs in other countries' scientific and technical work. The discussion will cover:

- the high and rising proportion of citations to nondomestic publications; and
- the status of U.S. science—as indicated by citations to it—in the context of other countries' total citations to nondomestic articles.

Figure 6-38.
Number of countries which shared at least one percent of their internationally coauthored articles with nation indicated: 1995–97



SOURCE: Institute for Scientific Information, Science Citation Index; CHI Research, Science Indicators database; NSF, special tabulation.

See appendix table 6-61. *Science & Engineering Indicators – 2000*

The international nature of scientific research is underscored by the high volume of citations to work done abroad. Averaged across all countries and fields, close to 60 percent of all citations in 1997 were to foreign research. This average had stood at 53 percent only 7 years earlier, a rather rapid rate of change. The increases could be seen for most countries and most fields. The world averages include the relatively lower rate of foreign citations found in U.S. papers, which in turn reflects the very large U.S. share of total world article output. (See beginning of "International Article Production: Counts, Collaboration, and Citations," above.) Many other countries, especially those with small indigenous science establishments, cited foreign works with higher frequency than these averages would indicate. (See appendix table 6-62.)

Particularly high rates of foreign citations were found in physics, a field noted for its high rate of international collaboration. In contrast, foreign citation rates of articles in engineering and technology and the social and behavioral sciences were well below the average, reflecting greater reliance on domestic research. (See appendix table 6-62.)

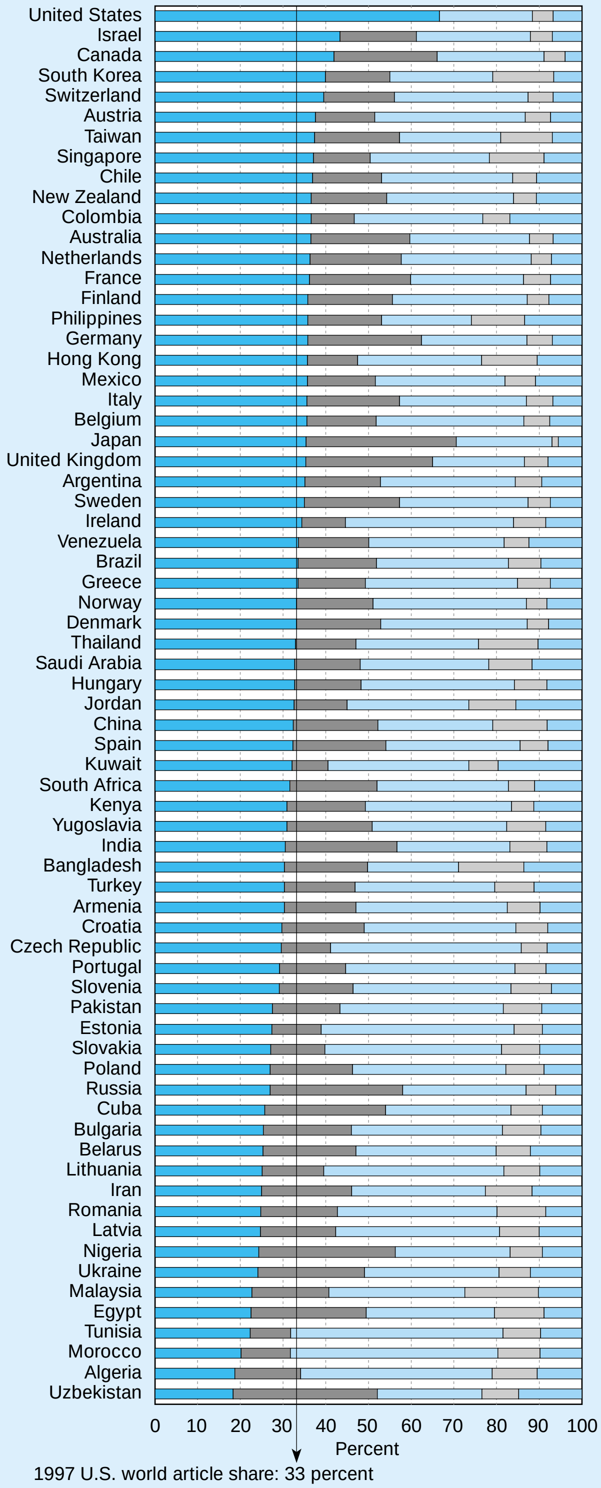
In a number of Asian countries, declines were registered in the share of citations to foreign sources overall. This was accompanied by a rise in citations to the scientific and technical literatures of other Asian nations. Intraregional citations increased from 6 percent of all references to nondomestic articles to 9 percent in less than a decade, from 1990 to 1997. As noted previously (see "Who Collaborates With Whom?" above), regional collaboration in Asia has been expanding over the period, from 13 percent to 18 percent of all Asian foreign collaborations. Seen in this light, these citation data point to continued growth of a more broad-based regional science capacity. (See appendix table 6-62.)

Citations to the U.S. literature in other nations' scientific and technical articles nearly always exceed the volume of citations to domestic research. (See Figure 6-39.) In most developed nations, such citations also run above the U.S. world article share. They drop below that mark for developing nations and for the former Soviet Bloc states, where access may be an issue.

Eliminating from consideration all countries' citations to their domestic articles adjusts for the well-documented tendency to favor domestic literature.[77] From the menu of available world science (not their own), to what extent do researchers in these nations select U.S. articles to read and cite? The proportion of U.S. articles among all citations to nondomestic literatures is very high and in most instances exceeds the U.S. share of world articles. (See figure 6-40.) For example, the U.S. article share in physics has declined from 28 to 22 percent since 1990, and the citations share (the average in all other countries' nondomestic citations) has dropped from 49 to 39 percent over the same period. (See text table 6-9.) However, after an approximate allowance is

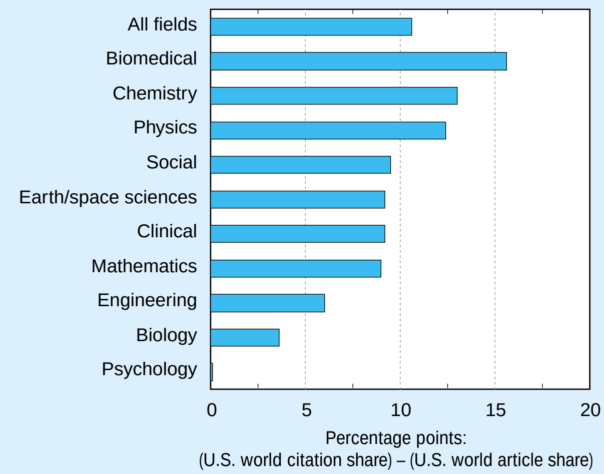
[77]After summing all countries' (except the United States') citations to nondomestic articles and calculating what percentage of these refer to U.S. articles, this percentage is compared to the U.S. world article share.

Figure 6-39.
Citations in selected countries' scientific and technical literature to U.S., own, and major regions' articles: 1997



See appendix table 6-61. *Science & Engineering Indicators – 2000*

Figure 6-40.
Citations to U.S. research in other nations' scientific and technical articles, relative to U.S. world article shares, by field



NOTE: Plotted values are the difference between the 1993 U.S. share of the world literature and the 1997 U.S. share of other nations' citations to foreign literature. For example, foreign citations to U.S. mathematics articles are about 9 percentage points higher than would be expected on the basis of the U.S. article share in the field.

SOURCE: Institute for Scientific Information, Science and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; NSF, special tabulation.

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made for time lags between publication and citation—here by comparing the 1997 citations share (39 percent) with the 1993 article share (27 percent)—U.S. physics articles remain cited well above the share expected based on article volume alone. (See appendix table 6-63.)

Citations on U.S. Patents to the Scientific and Technical Literature

Patent applications cite "prior art" that contributes materially to the product or process to be patented. Citations to such prior art have traditionally been to other patents; increasingly, these citations include scientific and technical articles. The percentage of U.S. patents which cited at least one such article increased from 11 percent in 1985 to 14 percent in 1990 and 25 percent in 1996.[78] This development attests to both the growing closeness of some research areas to practical applications and an increasing willingness of the U.S. Patent and Trademark Office (PTO) to award upstream patents. Thus, citations of scientific and technical articles on patents provide a good indicator of the growing linkage between research and innovative application, as judged by the patent applicant and recognized by PTO.[79]

[78]Personal communication with Francis Narin, CHI Research, Inc., and National Science Board (1998).

Text table 6-9.
Citations to foreign articles in the world's major scientific and technical journals, by field: 1990–97

Field	Citations to foreign articles (percent)			Citations to U.S. articles (percent of foreign citations)			U.S. share of articles (percent of world total)		
	1990	1993	1997	1990	1993	1997	1990	1993	1997
All fields	53	56	59	52	50	47	37	36	33
Physics	58	63	64	49	44	39	28	27	22
Chemistry	54	57	60	40	39	36	22	23	20
Earth/space sciences	52	54	58	53	51	49	39	40	36
Mathematics	50	53	56	50	50	47	41	38	32
Biology	50	53	57	42	42	37	37	33	30
Biomedical research	54	57	59	57	56	55	39	39	38
Clinical medicine	55	57	61	52	50	48	39	39	36
Engineering/technology	47	51	55	48	46	40	38	34	29
Psychology	37	38	42	66	63	58	60	58	55
Social sciences	33	35	40	66	64	62	55	53	49
Health/professional fields	23	25	31	71	68	65	70	69	63

NOTES: Citations are for a three-year period with a two-year lag; for example, 1997 citations are to 1993–95 articles. Foreign citations exclude those in U.S. journals.

SOURCES: Institute for Scientific Information, Science Citation and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, special tabulation. *Science & Engineering Indicators – 2000*

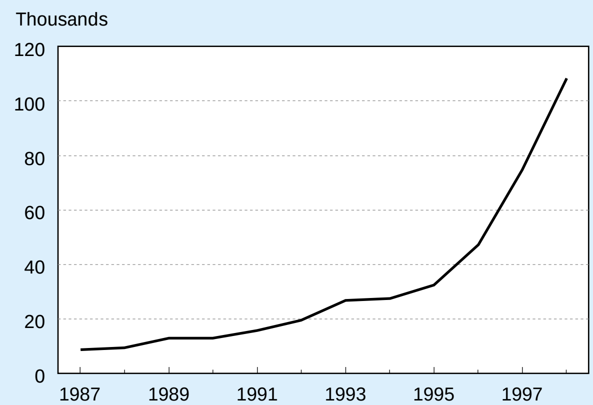
Citations to U.S. research articles included in the SCI set of journals were identified and classified by field and performer sector for all U.S. patents issued from 1987 through 1998. The number of such citations stood at 8,600 in 1987, more than doubled over five years, doubled again in less than four years (1996: 47,000), then doubled again in less than two years to reach 108,300 in 1998.[80] (See figure 6-41 and text table 6-10.) The rise in the number of citations held for all fields and for papers from all sectors. (See appendix table 6-64.)

The explosive growth of article citations on patents was rooted in enormous increases in the life sciences: from 2,400 to 55,900 in biomedical research in little more than a decade, and from 2,200 to 33,400 in clinical medicine. Consequently, even as the number of citations increased to articles in every field, the field shares shifted dramatically:

- Biomedical research rose from 28 percent in 1987 to 52 percent in 1998; clinical medicine from 26 to 31 percent.
- The combined share of physics, chemistry, and engineering and technology citations dropped from 43 to 15 percent.

Patent citations to academic articles rose faster than citations to industry or government authors, pushing the academic share of the total from 48 to 54 percent from 1987 to 1998. The academic sector's share of all article citations on patents increased particularly strongly in physics (from 29 to 41 percent), earth and space sciences (40 to 56 percent), and engineering and technology (26 to 46 percent)—fields with stagnating or declining industry article output. (See appendix tables 6-64 and 6-65.)

Figure 6-41.
Number of citations on U.S. patents to scientific and technical articles: 1987–98



NOTE: Changed U.S. Patent and Trademark Office procedures, greater ease of locating scientific and technical articles, and greater incentive to cite them may have contributed to some of these increases.

SOURCE: CHI Research, Inc. Science Indicators and Patent Citations databases; NSF, special tabulation.

See appendix table 6-64. *Science & Engineering Indicators – 2000*

[79]Some caveats apply. The use of patenting varies by industry segment, and many citations on patent applications are to prior patents. Industrial patenting is only one way of seeking to ensure firms' ability to appropriate returns to innovation and thus reflects, in part, strategic and tactical decisions, for example, laying the groundwork for cross-licensing arrangements. Most patents do not cover specific marketable products but might conceivably contribute in some fashion to one or more such products in the future.

[80]Some of the rise may reflect changed U.S. Patent and Trademark Office procedures, greater ease of locating the relevant prior art, and greater incentives to include all possible elements thereof. Nevertheless, the direction and strength of the trends reported here are congruent with those in academic patenting, discussed below. The number of citations reported here refer to articles published in a 12-year span, as follows: 1997 patent citations are to articles published in 1983 to 1994, and so forth.

Text table 6-10.
Number and distribution of citations on U.S. patents to the U.S. scientific and technical literature, by field

Citation year	Total	Physics	Chemistry	Earth & space	Mathematics	Clinical medicine	Biomedical research	Biology	Engineering & technology	All others
					Number of citations					
1987	8,618	1,286	1,181	105	0	2,221	2,390	168	1,242	23
1988	9,498	1,595	1,212	81	2	2,423	2,749	220	1,209	5
1989	12,988	2,356	1,536	119	2	3,190	3,976	304	1,458	44
1990	12,936	2,169	1,673	76	3	3,415	3,818	306	1,443	31
1991	15,720	2,424	1,921	123	2	4,205	5,199	437	1,401	4
1992	19,425	2,667	2,451	94	18	5,293	6,945	436	1,492	26
1993	26,721	3,024	3,027	93	21	7,393	10,735	548	1,850	26
1994	27,437	3,589	3,114	122	14	7,215	10,332	677	2,346	25
1995	32,536	3,366	3,689	134	19	9,173	12,719	812	2,593	27
1996	47,142	3,506	4,535	195	25	13,637	20,646	1,349	3,207	36
1997	74,839	4,150	6,218	207	30	22,649	36,397	1,508	3,589	85
1998	108,335	4,719	6,900	285	35	33,437	55,891	2,426	4,452	189
					Percent of citations					
1987	100	14.9	13.7	1.2	0.0	25.8	27.7	1.9	14.4	0.3
1988	100	16.8	12.8	0.9	0.0	25.5	28.9	2.3	12.7	0.1
1989	100	18.1	11.8	0.9	0.0	24.6	30.6	2.3	11.2	0.3
1990	100	16.8	12.9	0.6	0.0	26.4	29.5	2.4	11.2	0.2
1991	100	15.4	12.2	0.8	0.0	26.7	33.1	2.8	8.9	0.0
1992	100	13.7	12.6	0.5	0.1	27.2	35.8	2.2	7.7	0.1
1993	100	11.3	11.3	0.3	0.1	27.7	40.2	2.1	6.9	0.1
1994	100	13.1	11.3	0.4	0.1	26.3	37.7	2.5	8.6	0.1
1995	100	10.3	11.3	0.4	0.1	28.2	39.1	2.5	8.0	0.1
1996	100	7.4	9.6	0.4	0.1	28.9	43.8	2.9	6.8	0.1
1997	100	5.5	8.3	0.3	0.0	30.3	48.6	2.0	4.8	0.1
1998	100	4.4	6.4	0.3	0.0	30.9	51.6	2.2	4.1	0.2

NOTE: Count for 1987 patents is of citations to articles published in 1973-84; for 1988 patents to articles published in 1974-85; and so forth.

SOURCES: Institute for Scientific Information's Science Citation and Social Science Citation Indexes; CHI Research, Inc., Science Indicators database; and National Science Foundation, special tabulation.

See appendix table 6-64.

Science & Engineering Indicators – 2000

Examination of the sectoral patterns of patent citations reveals the prominent and growing role of biomedical research in the cited articles from every sector (ranging from 44 to 59 percent of all article citations), accompanied by strong or growing citation of papers in clinical medicine. (See appendix table 6-66.) The composition of citations to academic and industry articles, in particular, illustrates the key role of these areas of inquiry: Only 10 percent of citations to industry articles referred to physics, down from 29 percent a decade earlier. But 71 percent of patent citations to industry articles were to the life sciences, up from less than a quarter.

Further exploration of these trends was undertaken by Narin, Hamilton, and Olivastro.[81] Their study examined the citations on the front sheets of all 397,660 U.S. patents awarded in 1987–88 and 1993–94. While many citations were to other patents, about 430,000 referred to nonpatent materials; 242,000 were judged to be science references. In addition to the rapid increase in article citations on U.S. patents, the authors discovered a shortening interval between publication and citation and a large proportion of citations to publicly funded science (defined by the authors to include articles by academic, nonprofit, and government authors).[82] References tended to be to articles appearing in nationally and internationally recognized, peer-reviewed journals, including journals publishing basic research results, and to be field- and technology-specific.[83] The authors noted both national (U.S. patents citing U.S. authors with greater-than-expected frequency) and regional components in the patterns of citations.

Academic Patenting: Patent Awards, Licenses, Startups, and Revenue

Governments assign property rights to inventors in the form of patents to foster inventive activity that may have important economic benefits. The U.S. Patent and Trademark Office (PTO) grants such government-sanctioned property rights in the form of patents for inventions deemed to be new, useful, and non-obvious. This section discusses recent trends in academic patenting and income from these activities flowing to universities and colleges.[84]

[81]Narin, Hamilton, and Olivastro (1997).

[82]This latter finding is broadly consistent with results obtained by Mansfield (1991), focusing on academic science only and using a very different study framework and approach.

[83]See tables 2 and 3 in Narin, Hamilton, and Olivastro (1997).

Trends in academic patenting provide an indication of the importance of academic research to economic activity, which may well be growing even in the short term. The bulk of academic R&D is basic research, that is, not undertaken to yield or contribute to immediate practical applications. However, academic patenting data show that universities are giving increased attention to potential economic benefits inherent in even their most basic research—and that the U.S. PTO grants patents based on such basic work, especially in the life sciences.

A growing number of academic institutions are applying for, and receiving, protection for results of work conducted under their auspices. After slow growth in the 1970s, the number of academic institutions receiving patents increased rapidly in the 1980s from about 75 early in the decade to double that by 1989 and nearly 175 by 1997. This development, pronounced during the 1980s and more muted in this decade, reflected increases in the number of both public and private institutions receiving patents.[85] (See figure 6-42 and appendix table 6-67.)

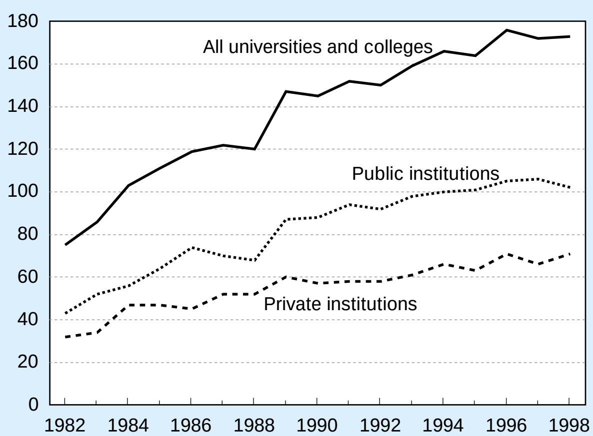
Starting in the early 1980s, the number of institutions outside the ranks of the largest research universities (defined here as the top 100 in total R&D expenditures) with patent awards increased at a rapid pace. The Nation's largest research universities represented 64 percent of all academic institutions receiving patents in 1985; their number had fallen to half by 1996.[86] Much of the broadening of the base of patenting institutions occurred among public universities and colleges. (See appendix table 6-67.)

Increasing university patenting and collaboration with industry have given rise to questions about possible unintended consequences—for universities and academic researchers—arising from these developments. Concerns have been expressed about potential distortions of the nature and direction of academic basic research, about contract clauses specifying delays or limitations in the publication of research results, and about the possibility of the suppression of research results for commercial gain. Unsettled questions also arise from faculty members' potentially conflicting economic and professional incentives in such arrangements. Universities as institutions may find themselves in a similarly ambiguous position as they acquire equity interests in commercial enterprises. In addition, scholars have asked whether patenting of government-sponsored research results may not in fact be detrimental to its intended goal of enhancing the transfer of new technologies.[87] These unsettled questions provide the backdrop for the rapidly rising numbers of academic patents.

The expansion of the number of institutions receiving patents coincided with rapid growth in the number of patent awards to academia, which rose from 589 in 1985 to 3,151 in 1998, accelerating rapidly since 1995. By the mid-1980s, the share of patents accounted for by the top 100 R&D-performing universities was about 77 percent of the total, as academic institutions started responding to provisions of the Bayh-Dole Act of 1980.[88] However, since the late 1980s, these large research universities have accounted for over 80 percent of all academic patents, a figure which increased to 89 percent by 1998. (See appendix table 6-67.)

The number of academic patents has risen tenfold, from about 250 annually in the early 1970s to more than 3,100 in 1998 (see figure 6-43), a far more rapid increase than for all annual U.S. patent awards. As a result, academic patents now approach 5 percent of all new U.S-origin patent awards, up from less than one-half of 1 percent two decades ago. The Bayh-Dole Act may have contributed to the strong rise in the 1980s, although university patenting was already on the rise before then. The creation of university technology transfer and patenting units, an increased focus on commercially relevant technologies, and closer ties between research and technological development may have contributed as well. A landmark Supreme Court ruling (Diamond v. Chakrabarty) allowing patentability of genetically-modified life forms may have been a

Figure 6-42.
Number of universities and colleges granted patents: 1982–98



NOTE: Numbers are lower-bound estimates because of some systemwide reporting.

See appendix table 6-67. *Science & Engineering Indicators – 2000*

[84]Chapter 7 presents a more comprehensive discussion of patented inventions in all U.S. sectors.

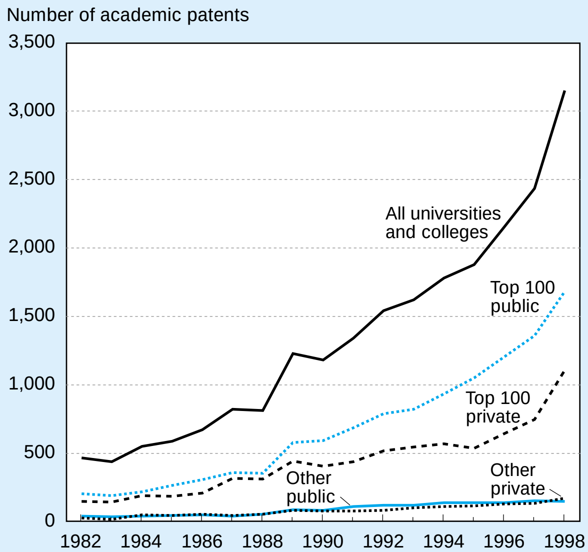
[85]Exact counts are difficult to obtain. Patent assignment depends on university practices which vary and can change with time. Patent assignment may be to boards of regents, individual campuses, subcampus organizations, or entities with or without affiliation with the university. The data presented here have been aggregated consistently by the U.S. Patent and Trademark Office starting in 1982. The institution count is conservative, since a number of university systems are included in the count and medical schools are often counted with their home institutions.

[86]These estimates are understated, since patent awards to some universities—for example, University of California, State University of New York—are generally recorded at the system level. But the trend reported here is calculated on a consistent basis.

[87]See Mazzoleni and Nelson (1998) and Ganz-Brown (1999).

[88]The Bayh-Dole University and Small Business Patent Act of 1980 permitted government grantees and contractors to retain title to inventions resulting from federally supported R&D and encouraged the licensing of such inventions to industry. Several empirical studies have recently examined effects of this law. See Henderson, Jaffe, and Trajtenberg (1998); and Mowery, Nelson, Sampart, and Ziedonis (in press)(2000).

Figure 6-43.
Number of academic patents granted: 1982–98



NOTE: The top 100 universities are defined as the institutions reporting the largest total R&D expenditures for 1997. Details do not add to total because of omission in detailed tally of academic patents held by unaffiliated agencies.

See appendix table 6-67. *Science & Engineering Indicators – 2000*

prime stimulus for the recent rapid increases, leading to greater PTO readiness to patent certain basic research outputs.

What is clear is that the vigorous increases in the number of academic patents largely reflect developments in the life sciences and biotechnology.[89] Two key trends in academic patenting are worth noting. First, a heavy concentration is evident in areas connected with the life sciences. Patents in a mere three technology areas or "utility classes"—all with presumed biomedical relevance[90]—accounted for 41 percent of the academic total, up from a mere 13 percent through 1980. (See figure 6-44.) Second, the growth in the number of academic patents was accompanied by a decrease in the number of utility classes in which they fall. In fact, academic patents are concentrated in far fewer application areas than are all U.S. patents. (See appendix table 6-68.)

Valuation of patents—especially of science-based ones—is difficult, and there are no guarantees that patents will have any direct economic value. Nevertheless, the motivation behind academic patenting is to protect intellectual property that is deemed valuable by the university, and academic institutions are increasingly successful in negotiating royalty and licensing arrangements based on their patents. While total reported revenue flows from such licensing arrangements remain low, compared to R&D spending, a strong upward trend points to the confluence of two developments: a growing eagerness of universities to exploit the economic potential of research activities conducted under their auspices, and readiness of entrepreneurs and companies to recognize and invest in the market potential of this research.

A 1992 survey by the U.S. General Accounting Office based on 35 universities found that they had substantially expanded their technology transfer programs during the 1980s. Typical licensees were small U.S. pharmaceutical, biotechnology, and medical businesses. During 1989–90, the reported income flows from these licenses were a mere $82 million. A more extensive survey has been conducted periodically since 1991 by the Association of University Technology Managers (AUTM).[91] The survey initially included only 98 universities, but has been augmented since 1993, with the additional institutions representing a coverage increase from 75 to 82 percent of academic R&D funds, from 85 to 90 percent of Federal academic R&D support, and from 80 to 91 percent of patents issued to academic institutions. (See text table 6-11.)

All indicators shown in this table point to an accelerating use of patenting by the Nation's universities and colleges. The number of new patents, license disclosures, applications filed, startup firms formed, and base of revenue-generating licenses and options are all growing at rapid rates, especially in the last two years shown. Key points are:

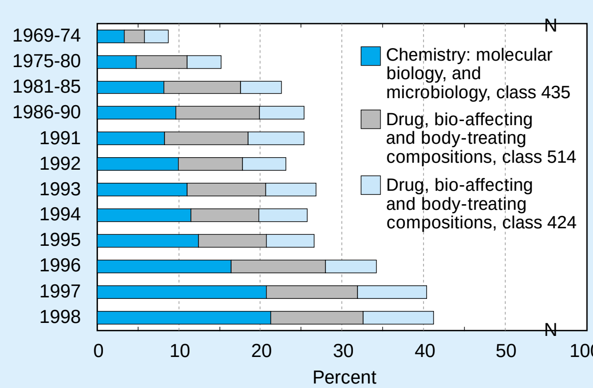
- University income from patenting and licenses is increasing steeply, reaching $483 million in 1997, although relative to academic research expenditures it remains low.
- About half of total royalties were classified by respondents as being related directly to the life sciences; about one-third was not classified by field; the remainder, labeled "physical sciences," appears to include engineering.

[89]See Huttner (1999).

[90]Utility classes numbers 424 and 514 capture different aspects of "Drug, bio-affecting and body treating compositions"; utility class number 435 is "Chemistry: molecular biology and microbiology." Patents are classified here according to their primary technology class.

[91]Association of University Technology Managers, Inc. (1998).

Figure 6-44.
Percentage of total academic patents in three largest academic utility classes: 1969–98, selected years



SOURCE: U.S. Department of Commerce, Patent and Trademark Office, Technology Assessment and Forecast Report, U.S. Universities and Colleges, 1969-98; NSF, special tabulation.

See appendix table 6-68. *Science & Engineering Indicators – 2000*

Text table 6-11.
Academic patenting and licensing activities

	1991	1992	1993	1994	1995	1996	1997
Finances (millions of dollars)							
Gross royalties	$130.0	$172.4	$242.3	$265.9	$299.1	$365.2	$482.9
New research funding from licenses	NA	NA	NA	$106.3	$112.5	$155.7	$136.2
Royalties paid to others	NA	NA	$19.5	$20.8	$25.6	$28.6	$36.2
Unreimbursed legal fees expended	$19.3	$22.2	$27.8	$27.7	$34.4	$46.5	$55.5
Invention disclosures, patent applications, patents							
Invention disclosures received	4,880	5,700	6,598	6,697	7,427	8,119	9,051
New patent applications filed	1,335	1,608	1,993	2,015	2,373	2,734	3,644
Total new patents received	NA	NA	1,307	1,596	1,550	1,776	2,239
Licenses, options, startup companies							
Startup companies formed	NA	NA	NA	175	169	184	258
Number of revenue-generating licenses, options	2,210	2,809	3,413	3,560	4,272	4,958	5,659
New licenses and options executed	1,079	1,461	1,737	2,049	2,142	2,209	2,707
Equity licenses and options	NA	NA	NA	NA	99	113	203
Survey coverage							
Number of institutions responding	98	98	117	120	127	131	132
Percent of total academic R&D represented	65	68	75	76	78	81	82
Percent of federally funded academic R&D represented	79	82	85	85	85	89	90
Percent of academic patents represented	NA	NA	80	89	82	82	91

NA = not available

NOTE: New research funding from licenses is defined as research funds directly related to signing of a specific license agreement.

SOURCE: Association of University Technology Managers, Inc. (AUTM), *AUTM Licensing Survey, Fiscal Year 1991–Fiscal Year 1997* (Norwalk, CT: 1998).

Science & Engineering Indicators – 2000

♦ The number of startups and of licenses and options granted increased strongly. Forty-one percent of new licenses and options went to large firms, 48 percent to small existing companies, and 11 percent to startups.

Conclusion

Over the past decade, the academic research and development enterprise has enjoyed strong growth. It continues to perform approximately half of U.S. basic research and is a major contributor to the nation's and the world's stock of scientific knowledge. Such knowledge appears to be increasingly tied to economic benefits. In turn, an increasingly technologically oriented economy is likely to place a premium on highly educated workers. Nevertheless, U.S. higher education is facing a number of challenges, some arising from within science and engineering, others from changes in the academic environment.

Higher education's overall financial environment has improved somewhat when compared to the recession years at the decade's turn, when many state governments combined flat or reduced appropriations with new accountability measures. Years of steep and unpopular increases in tuition and fees appear to lie in the past as well. Nevertheless, the Nation's universities and colleges continue to face cost pressures, even as nontraditional providers of teaching and training try to capture a growing share of traditional academic markets.

For many of the largest universities, a major uncertainty arises from the restructuring of the Nation's health care system. Some have responded by making structural changes in the relationships with their teaching hospitals, including one of turning them into for-profit ventures. Federal reimbursement changes are feared by many to have adverse effects on biomedical and clinical research and teaching.

For support of their R&D, academic institutions continue to rely heavily on the Federal Government, thus maintaining a certain dependence on implicit Federal priorities for the funding balance among fields. Universities' own resources are approaching one-fifth of their total R&D expenditures. However, in the face of financial pressures on all academic operations, this funding source cannot be expected to continue growing as a share of total academic R&D resources. Industry is often viewed as a potentially growing support source but has continued to supply less than 10 percent of the total funds, even as it has increasingly relied on academic R&D.

Demographic projections point to strong enrollment growth over the next decade and the continuation of several trends: more minority participation, growing numbers of older students, and greater proportions of non-traditional students. Issues of access, affordability, and fairness are likely to mix with considerations of institutional focus, mission, and strategy. Financial and other pressures will be part of the context in which they will unfold; undoubtedly, so will new service possibilities offered by technological developments, which carry their own costs and challenges.

These discussions will take place against the backdrop of increasing faculty retirements. As older faculty are leaving academia, hiring of young scientists and engineers can be expected to pick up further. However, the longer-term structure of this hiring is uncertain. Current trends suggest slower growth of the faculty segment than of other types of academic employment. Will universities and colleges shift the focus of their replacement hiring from tenure-track faculty positions into other, more flexible types of appointments?

The nature and goals of both undergraduate and graduate education are being debated. Are the current models appropriate, or should undergraduate education and graduate training allow for broader and more varied application of skills in the marketplace? Should graduate students be given more autonomy from their professors, perhaps by way of restructuring their modes of support? What is the appropriate role for the Federal Government in this support? Continued increases in the number of foreign students, vital for many graduate programs, cannot be taken for granted. Issues about the nature of graduate education join with questions of university missions and program organization.

The research universities are valued as a national resource: they educate and train large proportions of the Nation's scientists and engineers, embody the model of integrated graduate training and research, and conduct much of the nation's basic research. Yet questions abound. Is their graduate training developing a high-quality yet flexible workforce of scientists and engineers? Is it driven too much by research? Is their research enterprise too insular? Too driven by external demands from the Federal Government or industry? Does it cost too much? How can research be better connected to undergraduate education? With growing research involvement, smaller academic research performers face these same questions.

Answers to these and other questions will emerge gradually, as individual institutions respond to the challenges and opportunities they perceive. The Nation's universities and colleges have shown great ability to adapt to changed realities. In time, it will become possible to take stock of the changes and assess their extent. Many issues underlying these changes will persist, as higher education institutions try to find the appropriate balance among their many evolving functions.

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